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Norman G. Benson and
Ross V. Bulkley
Fishery Research Biologists

RESEARCH REPORT 62

UNITED STATES DEPARTMENT OF THE INTERIOR

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Frank P. Briggs, *Assistant Secretary for Fish and Wildlife*

FISH AND WILDLIFE SERVICE

Clarence F. Pautzke, *Commissioner*

BUREAU OF SPORT FISHERIES AND WILDLIFE

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ABSTRACT

Equilibrium yield of the cutthroat trout, *Salmo clarki lewisi* Girard, in Yellowstone Lake, Wyo., is determined from data on catch and spawning runs from 1945 to 1961. Changes in growth rate, spawning runs, mortality rates, and year-class strength are related to differences in total catch. Three stages of exploitation of the stock are defined, and the maximum safe catch or equilibrium yield is estimated at 325,000 trout. Management of the sport fishery according to equilibrium yield is discussed with reference to regulations, distribution of fishing pressure, planting, and interspecific competition. The Yellowstone River fishery is treated briefly.

EQUILIBRIUM YIELD AND MANAGEMENT OF CUTTHROAT TROUT IN YELLOWSTONE LAKE

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Equilibrium yield is one of the primary objectives of trout fishery management where wild fish are involved. This report presents a method for estimating maximum equilibrium yield and discusses the relations of yield to management of the stock of cutthroat trout (*Salmo clarki lewisi* Girard) in Yellowstone Lake, Wyo. The study is based mainly on data collected from 1945 to 1961 on the catch and spawning runs, but it includes other biological information on this trout population. Natural fluctuations in stock abundance are distinguished from those caused by fishing, and past management is evaluated.

Yellowstone Lake, in Yellowstone National Park, has one of the few native cutthroat trout stocks in the United States that have not had to compete with large populations of introduced fishes. The lake and tributaries make up a closed water system, as Yellowstone Falls (180 feet high) is located 15 miles below the lake. The National Park Service has prevented extensive development of the lake shore, and the lake ecology has remained relatively unaltered.

This study was essentially confined to the management of Yellowstone Lake, but the fishery in the 15 miles of the Yellowstone River from the outlet to the falls has also been reviewed.

The authors are now at the Bureau's North Central Reservoir Investigations, P.O. Box 139, Yankton, S. Dak.

The scope of the material in this report makes it advisable to describe briefly the subjects considered and their order of presentation. First, general background material is presented on the history of fishery investigations on Yellowstone Lake, fish cultural work, description of Yellowstone Lake, life history of cutthroat trout, and lake stocks. Second, the catch from 1950 to 1961 is discussed; this includes the number of fish caught, catch per man-hour, lengths, ages, and sexual maturity. Third, we discuss the changes in growth rate, spawning runs, mortality rates, and year-class strength during the study period and consider the causes thereof; changes caused by fishing are differentiated from those produced by natural conditions. Fourth, methods and calculation of maximum equilibrium yield are presented. Fifth, the management of this fish population according to equilibrium yield is discussed in respect to regulations, distribution of fishing pressure, interspecific competition, and planting. The last section includes the biology and management of the Yellowstone River fishery. Much of the data and some methods used are put in the appendixes to avoid complicating the presentation.

The manuscript was reviewed by Drs. Oliver Cope, William Sigler, John Neuhold, William Ricker, and Kenneth Watts, and by Orville Ball. Their suggestions and criticisms are gratefully acknowledged.

BACKGROUND DATA

Investigations

The cutthroat trout population in Yellowstone Lake was first mentioned by Hayden (1872), who reported that a single species of fish was in the lake, a trout which weighed from 2 to 4 pounds each. Jordan (1891) made a reconnaissance survey of the lake in 1889, and Evermann (1893) described the Yellowstone cutthroat trout in detail. Kendall (1915) and Smith and Kendall (1921) made further general studies on the biology of the cutthroat and its management. Unpublished reports were prepared by Schultz (1936),[1] Madsen (1940),[2] and Foster (1941).[3]

The U.S. Fish and Wildlife Service conducted more detailed biological studies from 1943 to 1946 on spawning runs and stocking methods under the direction of Dr. Stillman Wright, but the first detailed investigation on this cutthroat trout population was carried out by the Rocky Mountain Investigations of the Service from 1949 to 1961. Some recent publications dealing with the biology of the cutthroat and lake ecology are by Laakso and Cope (1956), Cope (1953, 1956, 1957a, 1957b), Ball (1955), Ball and Cope (1961), Benson (1960, 1961), Bulkley (1961), and Bulkley and Benson (1962).

Fish culture

A U.S. fish cultural station was operated on Yellowstone Lake from 1901 to 1953. Fish were trapped in tributary streams during their spawning runs, and eggs were collected and fertilized. Most eggs were used for stocking other waters in and outside Yellowstone National Park, but eyed eggs, advanced fry, and fingerlings were also planted in Yellowstone Lake and tributaries. The fingerlings were fed only a short time before stocking and were in the 1-inch class. A summary of the egg take and stocking in Yellowstone Lake and tributaries from 1940 to 1953 is shown in table 1. The number of spawners allowed to spawn naturally varied greatly from year to year and from stream to stream. Influences of planting and egg collecting on the fish stock are discussed later. Several programs to evaluate these plantings by fin clipping were never completed.

TABLE 1.—*Number of cutthroat trout eggs collected from tributaries of Yellowstone Lake and number planted in lake or in tributaries, by years, 1940 to 1953*

[In thousands]

Year	Number of eggs collected	Number planted in lake or tributaries		
		Eyed eggs	Advanced fry	Fingerlings
1940	43,000	963	3,963	1,752
1941	39,000	1,251	4,175	1,661
1942	25,000	2,001	3,339	1,567
1943	25,000	2,061	3,161	1,615
1944	24,000	800	3,200	1,125
1945	20,000	0	2,600	602
1946	24,000	0	3,075	608
1947	21,000	0	2,980	403
1948	19,000	0	550	0
1949	19,000	0	742	0
1950	18,000	625	1,011	0
1951	18,000	0	0	0
1952	15,000	0	0	0
1953	8,000	0	0	0

Native and introduced fishes

Except for the cutthroat trout, the only endemic species in the drainage is the longnose dace (*Rhinichthys cataractae* Valenciennes). The mountain whitefish (*Prosopium williamsoni* Girard) was stocked in the Yellowstone River above the falls in 1898 but did not survive. In 1908 and 1909, landlocked salmon (*Salmo salar sebago* Girard) and rainbow trout (*Salmo gairdneri* Richardson) were introduced into Yellowstone Lake, but neither had survived to 1915 (Kendall, 1915). Exotic fishes presently in the lake are the longnose sucker (*Catostomus c. catostomus* Forster),

[1] "Report of observations on the cutthroat trout of Yellowstone Lake in regard to stocking," by Leonard P. Schultz. U.S. Bureau of Fisheries typewritten report, August 18, 1936, 12 pp.

[2] "Report on age and growth of the cutthroat trout (*Salmo lewisi*) of Yellowstone Lake, Wyoming," by M. J. Madsen. U.S. Bureau of Fisheries typewritten report, 1939.

[3] "Preliminary report of Yellowstone Lake investigations, season of 1940," by Richard F. Foster. U.S. Fish and Wildlife Service typewritten report, plus 5 progress reports, 1941.

introduced about 1923, the redside shiner (*Richardsonius balteatus hydrophlox* Cope), introduced before 1955, and the lake chub (*Hybopsis plumbea* Agassiz), introduced before 1949. The longnose sucker is the only nontrout species widely distributed in the lake, but it is restricted to the littoral zone. The other species are confined to shallow lagoons, tributary streams, or protected shallow areas. The relations of the sucker and redside shiner populations to the cutthroat trout stock are discussed later.

Regulations

Fishing regulations before and during the 1920's allowed a limit of 20 fish per angler per day and limited fishing methods to hook and line. Following an increase in fishing pressure in the 1930's and until 1949 the daily limit was 10 fish. This limit was lowered to 5 fish in 1949 and to 3 fish in 1953. Length limits have never been used. Before 1953 the fishing season extended from May 30 to October 15. Since then the opening day has been June 15 on the lake and June 1 on the Yellowstone River; the closing day is October 15.

Yellowstone Lake

Yellowstone Lake (fig. 1) has a surface area of 136.7 square miles, a mean depth of 139 feet, a maximum depth of 320 feet, and a shoreline development of 3.04 (Welch, 1948). It lies at an elevation of 7,731 feet. The lake basin is volcanic in origin, and the limnological characteristics can best be described as oligotrophic. Total alkalinity ranges from 30 to 38 p.p.m., and conductivities (reciprocal megohms at 25° C.) range from 62 to 123. The lake freezes over each year from January to May, and summer surface temperatures rarely exceed 65° F.

Principal bottom organisms are *Gammarus lacustris* (Sars), *Hyallela azteca* (Saussure), and several species of tendipedids. The phytoplankton is dominated by diatoms, but a pulse of *Anabaena* occurs each August. The most abundant zooplankters are *Diaptomus shoshone* (S. A. Forbes), *Daphnia schoedleri* (Sars), and *Conochilus unicornis*. Plankton and bottom fauna species composition has not changed, to any measurable degree, from the time of an early reconnaissance study by Forbes (1893) in 1890 to the present time. Periodic temperature records from the Yellowstone Fish Cultural Station from 1920 to 1953 have also emphasized the stability of this environment. We have considered the lake environment as a constant when annual differences in the statistics of the trout stock are analyzed.

Fourteen major and 26 minor tributaries empty into the lake. Yellowstone River is the largest stream entering the lake and is the stream that drains the lake. Most tributaries are cold, clear alpine streams, although hot springs drain into several tributaries.

Life history of cutthroat trout

The life history of the cutthroat trout in Yellowstone Lake has been described in several of the papers cited previously and is reviewed briefly here. Cutthroat trout of age groups III to VII, but predominantly fish of age groups IV and V, migrate into tributary streams of Yellowstone Lake and the Yellowstone River from May through July to spawn. Studies with tagged trout from 1951 to 1953 suggest that up to 98.78 percent of the spawning fish are initial spawners (Ball and Cope, 1961). Repeat spawning in alternate years occurs over four times more frequently than in consecutive years. An average of 48 percent of the spawners die in the spawning streams from predation and other causes; the survivors move back into Yellowstone Lake within a few weeks after they enter the stream.

Eggs are deposited in gravel from a few days to several weeks after spawners enter the streams, and fry emerge from the gravel an average of 30 days after egg deposition. Some immatures migrate to the lake within 2 weeks after emergence, while

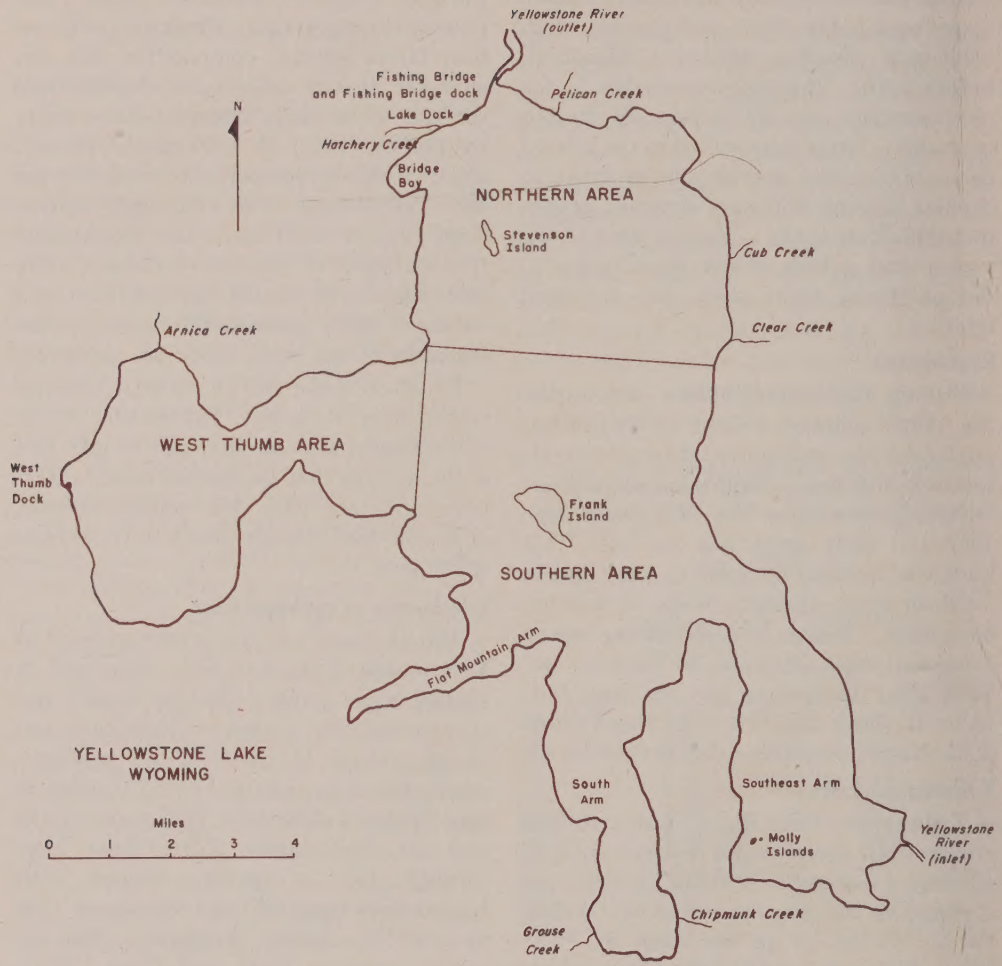

FIGURE 1.—Yellowstone Lake, showing areas and streams included in the study.

others remain in the streams for periods up to 2 years. Predation and other factors cause an estimated average mortality of 99.6 percent from the egg potential of the spawning population to the number of immatures that enter the lake. Mortality studies in Arnica Creek suggested a relatively high survival rate of 36.8 percent from the time that immatures leave the parent stream until they return as spawners. Both immature and adult trout showed strong homing tendencies (Ball, 1955).

Trout feed almost entirely on plankton and bottom fauna in the lake. Only 6 out of 694 stomachs examined contained fish (small cutthroat trout). There is a gradual transition from a plankton-bottom fauna diet to a diet predominantly of benthos in fish within the length range of 225 to 300 mm. Most trout are in the upper 45 feet of water during the summer, and few venture below the 75-foot depth. Small trout inhabit both the limnetic and littoral zones, while large trout are found predominantly in the littoral zone.

Fishing in spawning streams, except for the lower Yellowstone River, is not common, and the catch is taken almost entirely from the lake. A few trout enter the catch at age group II, but most trout caught are in age groups III, IV, and V.

Predation

The rate of natural predation in Yellowstone Lake must be considered when evaluating the causes of fluctuations in trout abundance over a period of time. The white pelican is the principal predator, but the black bear is also involved. Black bears consume a large number of trout during spawning, but the number of bears around Yellowstone Lake is maintained at a relatively constant level by the National Park Service. Double-crested cormorants are not common enought to be considered. Ball and Cope (1961) studied pelican predation and showed how it was related to spawning runs of trout. They suggested that the mortalities caused by pelicans alone exceeded fishing mortalities from 1950 to 1953.

Pelican predation will vary from year to year according to the number of pelicans. Pelican breeding is confined to the Molly Islands on Yellowstone Lake, and the number of young produced on these islands has been recorded by the National Park Service for some years. We have used these counts as a measure of the variation in amount of pelican predation. Murphy[4] reviewed the pelican count data from 1929 to 1959 (table 2), but stated that the accuracy of some of the counts may be open to question. He found that the number of young hatched increased during the 1930's to a high in 1946. Except for a low of 58 in 1950 the number hatched has ranged from 200 to 300 since 1946. He attributed the low numbers in 1931 and 1950 to normal population fluctuations, but the overall increase may be due to more rigorous protection on a national level. The data since 1950 do not suggest any significant changes in the pelican population, and we have not considered natural predation by pelicans as a variable in our analyses.

[4] "The Molly Island nesting colonies of Yellowstone Lake," by Joseph R. Murphy. Unpublished mimeographed report to National Park Service, 9 pp. 1959.

TABLE 2.—*Hatch of white pelicans on Molly Islands, for specified years, 1929 to 1960*

Year	Count of recently hatched birds
1929	134
1930	170
1931	54
1932	100
1936	180–200
1946	374
1947	228
1949	255
1950	58
1951	200 (banded)
1952	300 (est.)
1959	257
1960	[1]275

[1] Data courtesy of Robert McIntyre, Chief Park Naturalist, Yellowstone National Park.

Fishing stocks

The term "stock" in this paper refers to a group of subpopulations as defined by Marr (1957). His definition of a subpopulation could apply to the progeny of each spawning stream in Yellowstone Lake, since the homing instinct is strong.

Analyses of the lake population would be simplified if all data collected could be viewed as coming from a single stock, but several factors have made it advisable to consider the northern area and West Thumb as two distinct fishing stocks (fig. 1). These two stocks were studied separately because (1) each is supplied largely from a different group of spawning streams as shown from tagging of post-spawners, (2) they differ in strength of year classes, (3) they differ in seasonal recruitment into the fishery, and (4) they differ in age composition of the catch. There is not enough fishing pressure in the southern area at the present time to define it as a fishing stock. Some of the differences between stocks are described below, but more complete data are presented later.

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The relations between the trout from five spawning streams and these two fishing areas from 1949 to 1953 were determined from tagging. Ball and Cope (1961) studied the dispersal of 18,836 tagged postspawners from five spawning streams (fig. 1). Trout captured during the same year as they were tagged were found closer to the spawning stream than those captured during the second or third year, and results from all years showed the same general movements. Trout tagged in Pelican Creek, Clear Creek, lower Yellowstone River, and near Fishing Bridge were primarily captured in the northern area. Trout tagged in Chipmunk and Grouse Creeks were often captured in the lightly fished southern area, but a large number were recovered in West Thumb during August of the year of tagging or the following year. Most Arnica Creek tags were recovered in West Thumb. Assuming that the movement of postspawners is similar to that of prespawners, the northern area stock is composed mainly of fish spawned near the location of fishing, while the West Thumb stock consists of locally spawned fish plus fish from spawning streams in the southern part of the lake.

Year-class strength of the catch varies widely because of this difference in the source of fish contributing to the catch in the two areas. Bulkley and Benson (1962) analyzed the causes and variance of the strength of year classes in Pelican and Chipmunk Creeks. The strength of year classes of spawners at Pelican Creek is correlated significantly ($r=.825$, $d.f.=6$) with the catch at Fishing Bridge, and heavy exploitation in the northern area influenced the Pelican Creek spawning runs. Pelican Creek is not as important a spawning stream as the Yellowstone River for the northern area, but factors influencing year-class strength in Pelican Creek must be similar to those influencing the entire stock of the northern area. The West Thumb catch is derived from a large number of relatively small spawning streams, and the year-class strength of the catch does not follow closely any of the sampled streams. The reason for the close agreement in year-class strength between spawning streams and catch in the northern area and the lack of a similar agreement in West Thumb is suggested in data from Bulkley (1961). Spawning streams that are in close proximity to each other are more similar in the strength of their year classes than streams that are widely separated.

The West Thumb catch is rather evenly distributed throughout the fishing season, while the catch in the northern area is heaviest during the spawning period and decreases rapidly after the middle of July. The northern area catch has more old fish than West Thumb because it is more dependent on spawning migrations.

CATCH

Number caught

Early records of the sport fish catch from Yellowstone Lake cannot be considered too reliable, since they were collected by interviews at the gates of the park. They give a general picture of the fishing intensity and show the increase from 1925 to 1944. The average annual catches for 5-year periods were as follows: 1925–29, 69,000; 1930–34, 93,518; 1935–39, 140,697; and 1940–44, 117,697.

An intensive creel census (Moore et al., 1952; Cope, 1957a) was conducted from 1950 to 1961. This census sampled segments of the fishery such as shoreline, rowboats, trailer boats, etc., separately, and the total catch and fishing effort is estimated from the sum of all segments. From 1950 to 1959 the catch increased from 200,015 to 393,497 fish and the fishing pressure from 292,989 to 526,728 hours (table 3). The increase was continuous except for 1953 and 1954, when the catch decreased owing to the lowering of the

creel limit from 5 to 3 fish. Both the catch and the fishing pressure dropped in 1960. The drop in 1960 was related to a general decrease in fishing pressure and was not due to poor fishing. Fishing pressure in hours fluctuated less regularly than catch, but varied from 292,989 in 1950 to 526,728 in 1959.

TABLE 3.—*Estimated catch by areas and for entire lake and estimated fishing pressure for entire lake, by years, 1950 to 1961*

Year	Number of trout caught				Total hours of fishing
	Northern area	West Thumb area	Southern area	Entire lake	
1950	144,816	48,575	6,624	200,015	292,989
1951	147,999	52,085	8,171	208,255	353,090
1952	170,255	63,885	11,137	245,277	402,989
1953	129,529	38,819	27,525	195,873	332,684
1954	148,171	53,702	14,060	215,933	333,004
1955	191,647	78,276	16,133	286,056	445,206
1956	182,999	86,472	20,750	290,221	500,799
1957	187,462	92,174	21,519	301,155	418,963
1958	219,036	105,155	24,836	349,027	474,951
1959	250,310	117,171	25,986	393,467	526,728
1960	181,588	85,953	27,357	294,898	407,327
1961	192,211	97,114	23,269	312,594	497,664

Fishing pressure on Yellowstone Lake is not distributed evenly, owing to lack of easy access to the southern parts of the lake. Since the creel-census information was collected by sampling segments of the fishery separately, it was possible to break down quite accurately the catch from the three areas of the lake designated in figure 1 (method in appendix A). From 1950 to 1960 an average of 65.5 percent of the cutthroat trout were caught in the northern area (34.7 square miles), 27.6 percent in West Thumb (26.1 square miles), and 6.9 percent in the southern area (75.8 square miles). Although the catch has increased more in West Thumb and in the southern area than in the northern area in recent years, the overall distributional pattern has not changed greatly.

Catch per man-hour

Royce and Schuck (1954), Schaefer (1957), and other workers have used catch per unit of effort as an important statistic for calculation of stock density and for management purposes. We have found catch per man-hour to be an unreliable index of stock density in the Yellowstone Lake fishery because there were too many factors other than stock density that influenced rate of catch. Catch per man-hour did not vary greatly from 1950 to 1961 even with a tremendous increase in catch (table 4). For shoreline anglers, it was usually about 0.5 fish per hour, and for boat fishermen it varied from 0.5 to 1.0 fish per hour. There were no consistent relations between catch per man-hour and total catch for rental and guide boat anglers, shoreline anglers, and private trailer boat anglers. This lack of relation could not have been due to error in the collection of data for the shoreline fishery because census clerks actually observed fishermen and did not

TABLE 4.—*Catch and catch per man-hour by rental and guide boats, shoreline fishermen, and private trailer boats, by years, 1950 to 1961*

Year	Rental and guide boats		Shoreline		Private trailer boats	
	Number of trout caught	Catch per man-hour	Number of trout caught	Catch per man-hour	Number of trout caught	Catch per man-hour
1950	83,351	0.700	55,370	0.649	50,377	1.020
1951	90,442	.670	48,966	.406	54,857	.980
1952	102,210	.722	53,423	.404	75,457	.802
1953	62,364	.659	64,116	.522	50,118	.680
1954	72,369	.737	71,919	.616	51,222	.680
1955	89,470	.756	97,831	.559	80,270	.698
1956	94,315	.898	65,383	.342	110,937	.658
1957	104,786	.816	63,286	.536	115,141	.808
1958	93,354	.752	81,210	.530	149,667	.765
1959	105,277	.895	140,102	.603	124,421	.718
1960	76,120	.924	65,539	.503	126,109	.787
1961	99,795	.856	98,954	.560	93,632	.541

depend upon interviews. Two factors that were known to have seriously influenced catch per man-hour in the Yellowstone fishery were year-to-year variations in availability of the stock and a major change in fishing gear during the study period.

Most of the angling pressure on Yellowstone Lake is exerted on fish highly concentrated near shore in spawning migrations. Each year almost half of the catch from the shoreline and from rental boats at Fishing Bridge has been made during the first 4 weeks of the angling season (table 5). As the fish disperse after spawning they become more difficult to locate, and catch per man-hour decreases. Timing of the spawning period in relation to opening of the fishing season seriously influences the seasonal catch per man-hour, although this timing factor cannot be accurately evaluated. In years such as 1954, when spawning was delayed, opening of the fishing season coincided with the peak of the spawning period, and catch per man-hour remained high until the spawners dispersed. In years when environmental conditions were suitable for early spawning, such as 1951, many fish had spawned and commenced dispersing or had passed into spawning streams closed to angling before the fishing season opened. Catch per man-hour was correspondingly lower in these years, not because of reduced stock density in the lake, but because of earlier dispersal from the fishing area of a highly concentrated segment of the population.

Unusually high water levels in 1956 influenced catch per man-hour of shoreline fishermen, although the influence of water levels was not clearly evident during other years (fig. 2). Water levels in 1956 probably reduced availability of the cutthroat trout to shoreline anglers only, as boat fishermen did not experience a drop in rate of catch that year (table 4).

A major change in angling gear also occurred during the study period, with an ensuing increase in gear efficiency. From reports of concessionaires and sporting goods dealers, spinning gear was first introduced into the Rocky Mountain area around 1949. It did not become common on Yellowstone Lake until 1953 and 1954. The increase in catch per man-hour by shoreline fishermen after 1953 shown in table 4 is believed to have been caused partly by the increase in use of spinning gear. Spinning gear allows an angler to cast farther from shore with lighter lures. The introduction of newly designed fishing lures may also have influenced catch per man-hour, but the amount of influence is unknown.

Bulkley (1961) showed that growth rates increased from 1950 to 1956, and he could only attribute this increased growth rate to decreased stock density. Additional data presented in this paper support

TABLE 5.—*Percentage distribution by 2-week periods for anglers, catch, and catch per man-hour of shoreline and Fishing Bridge rental boats, 1954, 1955, and 1956*

[Angler and catch data given as percentages]

Two-week period	1954			1955			1956		
	Anglers	Catch	Catch per man-hour	Anglers	Catch	Catch per man-hour	Anglers	Catch	Catch per man-hour
June 15–28	18.1	19.5	0.97	20.0	21.9	0.63	16.3	23.1	0.62
June 29–July 12	26.0	28.0	.79	25.3	25.7	.69	21.9	23.2	.62
July 13–26	18.5	20.0	.44	22.8	24.0	.51	17.4	21.2	.40
July 27–Aug. 9	20.4	16.3	.39	12.7	12.3	.37	26.8	15.3	.28
Aug. 10–23	7.9	10.2	.32	12.5	10.2	.26	12.5	13.4	.27
Aug. 24–Sept. 6	9.1	6.0	.24	6.7	5.9	.24	5.1	3.8	.18
Total number	87,433	137,321	----------	131,358	171,988	----------	160,457	147,761	----------

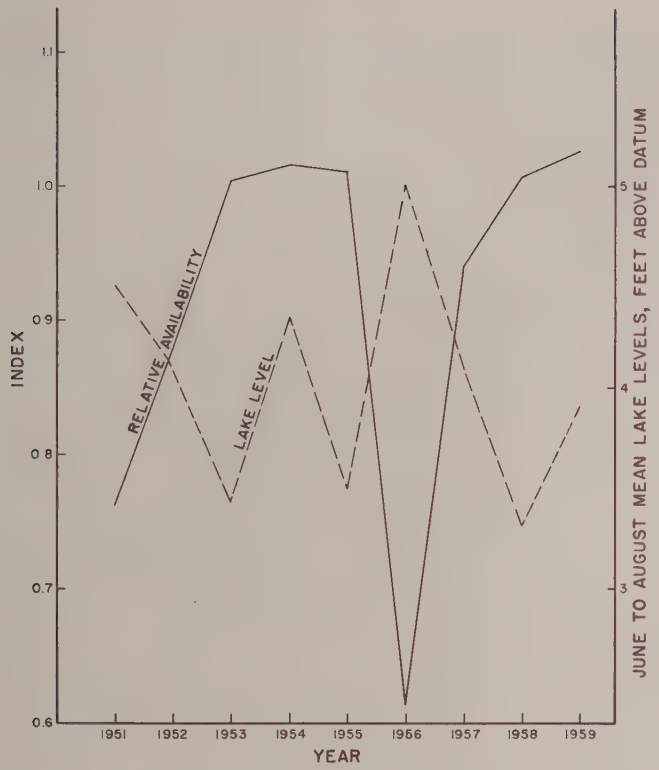

FIGURE 2.—Availability of cutthroat trout to shoreline anglers on Yellowstone Lake (solid line) as compared with mean monthly lake water levels from June to August (broken line), 1951 to 1959. Lake levels in feet above datum. Relative availability index from Rounsefell and Everhart (1954, p. 99).

his conclusion. Catch per man-hour has not decreased with a lower stock density, because as stock density has decreased gear efficiency has increased. Variations in timing of the spawning period and in water levels have further clouded the relation between catch per man-hour and stock density. These factors have made it impossible to utilize catch per unit of effort as a reliable index to the condition of the stock in Yellowstone Lake.

Lengths

Cope (1953) discussed mean total length measurements of the catch from 1950 to 1952 and found significant variations among years. Lengths from 1950 to 1961 show similar variation (table 6), and the causes of these variations are shown later to be related to growth rate, age composition, and year-class strength. The significant point on length data is that most of the catch during all years was between 300 and 400 mm. in total length. The means varied from 336.7 to 357.8 mm., and the means plus or minus one standard deviation ranged from 296.7 to 396.8 mm. Few fish were caught below 200 mm. or above 500 mm. Thus the stock available for sport fishing exploitation is restricted to a relatively small length range. The maximum length is limited by the maximum size attainable in the stock, and the minimum length is limited by the low availability of fish below 275 mm.

Age composition

The scale samples from Fishing Bridge dock have been assumed to represent the entire northern area stock. Several scale-sample collections from fishing areas other than Fishing Bridge in the northern area (*e.g.* Lake Dock, Bridge Bay) were compared with the Fishing Bridge samples, and no significant differences were found. The West Thumb dock samples have been applied to the entire West Thumb stock for the same reason.

TABLE 6.—*Total length of cutthroat trout caught from Yellowstone Lake, by years, 1950 to 1961*

[In millimeters]

Year	Number of trout in sample	Mean total length	Range in length		Standard deviation
			Minimum	Maximum	
1950	1,931	345.1	205	470	28.2
1951	1,063	343.2	215	455	39.3
1952	1,061	336.5	205	500	39.8
1953	711	345.7	195	470	39.5
1954	1,395	337.7	205	450	38.1
1955	1,946	343.6	200	505	38.7
1956	1,668	348.7	210	455	34.3
1957	634	353.3	205	455	33.5
1958	676	357.8	185	480	39.0
1959	2,349	353.9	215	470	38.4
1960	1,683	346.3	210	450	38.5
1961	2,478	344.2	225	460	36.2

Bulkley (1961) analyzed the age composition of the catch from 1950 to 1959, and his data are summarized as follows (table 7): (1) Age groups IV and V make up most of the catch, although age group III was significant in all years; (2) there were more older fish caught at Fishing Bridge than at West Thumb because a large part of the former fishery is dependent upon a spawning concentration; (3) relative abundance of age groups in the catch from both areas up until 1957 was related to year-class strength; and (4) there were fewer fish of age groups VI and VII in the catch after 1953 than in earlier years.

The difference in age composition between the West Thumb and Fishing Bridge fisheries is of a seasonal nature since spawning concentrations are largely dispersed after the middle of July (table 8). Up until July 11, fish of age groups V, VI, and VII are much more common at Fishing Bridge than at West Thumb, but there are no consistent differences between areas after that time. Fish of age groups II and III increase in importance as the season progresses, owing to recruitment.

Age compositions of the northern area and West Thumb catches from 1950 to 1961 are presented in figure 3. Before 1956, age composition of the northern area catch was not related to size of catch. The 1948 year class was strong at age IV and weak at age V. The 1949 year class contributed strongly at age III, weakly at age IV, and strongly at age V. The 1950 and 1951 year classes contributed weakly at ages III and IV, but strongly at age V. This haphazard entrance of age groups into the catch is probably indicative of a lightly exploited fishery. It also indicates varying rates of exploitation during these years. Stroud's (1948) data on Norris Reservoir in Tennessee showed a similar lack of trends, and this reservoir was known to be lightly exploited. Ricker (1954, p. 583) described similar oscillations for multiple-age spawning stocks.

Beginning in 1956, the catch of age group IV fish began to increase significantly, and this trend continued until 1959. The 1953 year class entered the catch strongly at ages IV and V. The 1954 and 1955 year classes entered the catch strongly at age IV but weakly at age V. The 1956 year class entered the catch strongly at age III, and the 1957 year class entered the catch strongly at ages II, III, and IV. The 1958 year class also entered the catch strongly at age III.

In the West Thumb fishery, the catch of age group IV fish increased steadily from 1953 to 1959, which coincided somewhat with the increased catch during those years. The 1958 West Thumb catch contained the largest recorded number of age group V fish, followed by 3 years with relatively few age group V fish in the

TABLE 7.—*Age composition of catches from Fishing Bridge and from West Thumb docks, by years, 1950 to 1961*

Year of capture and location	Percent in age group—						Mean age (years)	Mean length (mm.)
	II	III	IV	V	VI	VII		
1950:								
Fishing Bridge	1.0	13.1	37.9	37.2	10.1	0.7	4.44	358.9
West Thumb	6.4	34.2	24.8	30.4	4.0	.2	3.92	338.2
1951:								
Fishing Bridge	2.0	13.5	34.0	36.3	13.5	.7	4.48	349.6
West Thumb	1.6	33.9	40.7	21.3	2.2	.3	3.90	337.8
1952:								
Fishing Bridge	3.0	30.9	39.3	23.4	3.4	----	3.93	338.1
West Thumb	2.8	32.8	37.4	22.0	3.6	1.4	3.87	323.6
1953:								
Fishing Bridge	5.9	21.3	30.8	35.3	6.1	.6	4.22	350.8
West Thumb	2.0	30.0	43.5	19.7	4.8	----	3.96	331.8
1954:								
Fishing Bridge	7.4	18.8	30.1	39.3	4.4	----	4.14	339.4
West Thumb	6.2	28.5	44.0	19.3	2.0	----	3.82	332.0
1955:								
Fishing Bridge	3.0	20.1	26.9	41.3	8.7	----	4.23	347.2
West Thumb	6.8	32.0	39.4	19.0	2.5	.3	4.06	339.0
1956:								
Fishing Bridge	.8	18.4	43.0	33.6	4.2	----	4.21	352.3
West Thumb	----	30.5	46.2	22.3	1.0	----	3.94	344.0
1957:								
Fishing Bridge	1.4	12.3	53.5	30.8	2.0	----	4.20	353.2
West Thumb	.7	13.5	47.4	36.3	2.1	----	4.26	353.3
1958:								
Fishing Bridge	1.0	10.5	46.3	38.1	4.0	----	4.36	357.6
West Thumb	2.0	13.3	48.5	34.6	1.6	----	4.28	358.0
1959:								
Fishing Bridge	8.1	20.0	54.4	17.4	.1	----	3.81	355.5
West Thumb	1.3	20.2	68.0	10.4	.1	----	3.88	353.2
1960:								
Fishing Bridge	3.2	32.4	49.5	14.6	.4	----	3.77	345.7
West Thumb	4.1	29.7	53.7	11.1	1.4	----	3.76	347.4
1961:								
Fishing Bridge	.9	26.8	60.8	11.5	----	----	3.83	340.5
West Thumb	1.7	27.1	59.2	11.9	.1	----	3.82	345.4

TABLE 8.—*Age composition of catches from Fishing Bridge and from West Thumb docks for three periods of angling season, by years, 1950 to 1959*

Year and location of catch	For period June 15 to July 11,[1] percent in age groups—			For period July 12 to August 8, percent in age groups—			For period August 9 to September 5, percent in age groups—		
	II, III	IV	V, VI, VII	II, III	IV	V, VI, VII	II, III	IV	V, VI, VII
1950:									
Fishing Bridge	6.2	32.6	61.2	21.0	43.8	35.1	32.6	49.2	18.1
West Thumb	21.6	30.6	47.7	85.2	7.4	7.3	80.0	12.0	8.0
1951:									
Fishing Bridge	1.7	18.1	80.1	29.5	27.4	43.1	31.7	55.3	13.0
West Thumb	30.0	45.0	25.0	41.6	39.4	19.0	31.6	43.1	25.3
1952:									
Fishing Bridge	13.4	37.8	48.8	42.5	43.5	14.0	50.4	33.6	16.0
West Thumb	22.7	40.1	37.2	29.9	36.3	33.8	47.8	32.9	19.2
1953:									
Fishing Bridge	31.6	42.4	26.0	25.8	37.6	36.6	39.2	41.9	18.9
West Thumb	20.4	48.0	31.6	36.6	41.6	21.8	46.7	38.3	15.0
1954:									
Fishing Bridge	14.1	25.3	60.6	30.7	39.8	29.5	45.5	29.5	25.0
West Thumb	28.2	47.5	24.3	36.2	40.8	23.0	34.6	46.0	19.3
1955:									
Fishing Bridge	5.5	26.0	68.5	50.4	28.8	20.7	----	----	----
West Thumb	16.2	45.9	37.9	52.5	36.0	11.5	41.6	51.8	6.6
1956:									
Fishing Bridge	12.3	36.9	50.8	34.5	45.4	20.0	21.7	55.0	23.3
West Thumb	26.4	49.1	24.5	31.0	44.3	24.7	50.0	36.4	13.6
1957:									
Fishing Bridge	6.0	46.4	47.6	20.3	57.2	22.5	17.9	58.2	23.9
West Thumb	11.3	50.8	37.9	12.7	42.7	44.5	23.2	50.0	26.8
1958:									
Fishing Bridge	4.6	45.6	49.7	32.5	46.5	20.9	18.5	50.0	31.5
West Thumb	12.0	49.1	38.9	17.3	51.8	30.9	20.0	36.0	44.0
1959:									
Fishing Bridge	9.7	58.9	31.4	20.9	54.5	24.5	71.9	28.1	0.0
West Thumb	10.6	69.9	19.5	29.0	65.4	5.6	14.0	57.9	28.1

[1] In 1950, 1951, and 1952, data were collected from May 30 to July 11.

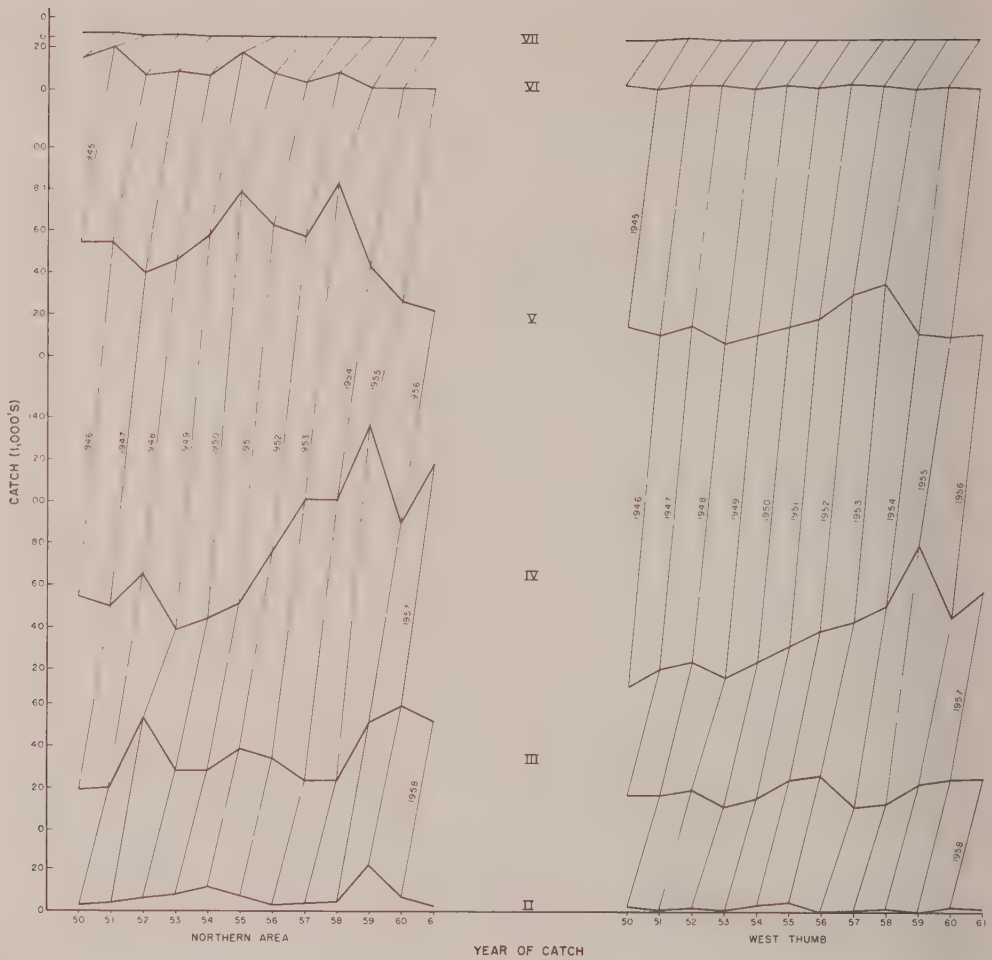

FIGURE 3.—Age composition of the northern area and West Thumb catches, 1950 to 1961. Slanting lines connect year classes.

catch. The 1953 year class contributed strongly to the catch at ages II, III, IV, and V. The 1955 year class contributed strongly at age IV, but few fish were left at age V in 1960. In both areas the general trend has been an increase in the precentage of fish of ages II, III, and IV in the catch and a decrease in fish of age groups VI and VII.

Maturity

Knowledge of the maturity of the catch is necessary for management of this fishery because the length range of the catch is small, the age composition of the catch and spawning runs are similar, and it is essential to preserve adequate spawning stocks for natural reproduction. A mature fish by our definition is one which has spawned previously, is spawning, or will spawn in the year of capture.

The maturity of the catch was determined by direct observation of fish caught before July 15, when the stage of maturity could be easily distinguished. Maturity of the entire season's catch was determined by adding a growth increment as explained

in appendix B. Most of the catch is mature fish with percentages by year ranging from 64.26 to 84.76 (table 9). This condition would be expected since so much fishing is dependent upon spawning concentrations. Cutthroat trout in Yellowstone Lake become available to the fishery at only a slightly smaller size than when they enter the spawning runs. These data on maturity disagree partially with the fishing and natural mortality rates in the lake obtained from tagging of spawners by Ball and Cope (1961). They calculated the fishing mortality of postspawners from spawning streams to be a maximum of 15.2 percent, and their data indicate that the fishery is dependent almost entirely on prespawning fish. Their term "prespawners" must include immature fish, mature fish on their initial spawning migration, and fish that have spawned previously. Tagging mortality after the trout left the spawning stream was not evaluated in that study. A comparison of returns to spawning runs of 2,561 tagged and 3,928 fin-clipped spawners in Arnica Creek in 1952 and 1953 showed that tagged fish experienced an average of 171 percent higher apparent mortality than fin-clipped fish. This discrepancy would explain the low number of tagged postspawners that were recovered in the catch.

TABLE 9.—*Percentage of mature fish in the catch at Fishing Bridge and at West Thumb docks, by years, 1950 to 1961*

Year	Percent mature in catch at—		Mean percent mature
	Fishing Bridge	West Thumb docks	
1950	84.31	65.70	75.01
1951	75.71	66.89	71.30
1952	67.52	66.81	67.17
1953	74.34	64.53	69.44
1954	70.91	64.26	67.59
1955	71.93	71.76	71.85
1956	79.65	75.54	77.59
1957	84.76	78.74	81.75
1958	82.95	82.81	82.88
1959	80.39	76.88	78.64
1960	76.87	74.49	75.68
1961	71.83	73.55	72.69

CHANGES IN THE POPULATION

Measurements of growth rates, spawning runs, mortality rates, and year-class strength are available on the Yellowstone Lake cutthroat stocks from 1945 to 1961. This section discusses the fluctuations in these measurements with respect to whether they were caused by fishing or by natural fluctuations in abundance.

Growth rate

Bulkley (1961) studied growth rate of cutthroat trout from Yellowstone Lake from 1946 to 1958. These data can be briefly summarized as follows: (1) All growth-rate changes appeared to be caused by differences in stock density; (2) growth rates of fish from different parts of the lake were similar from 1953 to 1955; (3) growth rates were similar for both sexes; (4) the long-term trend showed an increase in growth to 1956 and a leveling off in 1957 and 1958; (5) the increase in rate of growth occurred only among fish of age groups IV, V, and VI, which were the age groups most heavily exploited by the fishery.

In the present study, data on growth rate from 1958 to 1960 were included, and all data were separated by area (fig. 4, app. C). The increase in growth was consistent for combined age groups with a leveling off from 1956 to 1958 followed by a drop in 1959. The northern area stock showed another increase in 1960. When growth rate is compared with data on age composition of the catch (fig. 3), size of catch (table 3), and mortality rates presented later, the reason for the drop in mean growth rate in 1959 becomes apparent. Extremely heavy exploitation of the 1955 year class at age IV occurred in 1959 which removed both slow- and fast-growing fish and almost eliminated this year class from the stock. Samples from years previous to 1959 contained a larger percentage of fast-growing fish and are not directly comparable with the 1959

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sample. The very large catch in 1958 and 1959 also caused an increase in growth rate of fish of age groups II and III, particularly in the northern area.

When growth rate for combined age groups is plotted with the catches for the northern area and for West Thumb (fig. 5), it can be seen that the increase in growth rate was closely related to size of the catch. Only a decreased stock density could explain this relation. For yield considerations we have assumed that the optimum growth rate for the catchable stock in this environment was reached during the period from 1956 to 1959. Optimum growth rate by our definition means the maximum sustained growth rate that can be attained by the catchable stock in Yellowstone Lake under present environmental conditions. Growth rate of the northern area stock was higher in 1960 than this optimum level, but it is questionable whether this high rate of growth can be maintained. We have assumed that optimum growth rate was reached in 1956 because the growth rate did not continue to increase in spite of large increases in the catch from 1957 to 1959. A further decrease in stock density occurred during this period because of the recruitment of several weak year classes to the fishery, heavy exploitation of these year classes, and a reduction in size of several spawning runs.

An increase in growth rate may be undesirable if it is not accompanied by earlier age of maturity, as heavy exploitation of prespawning fish can result.

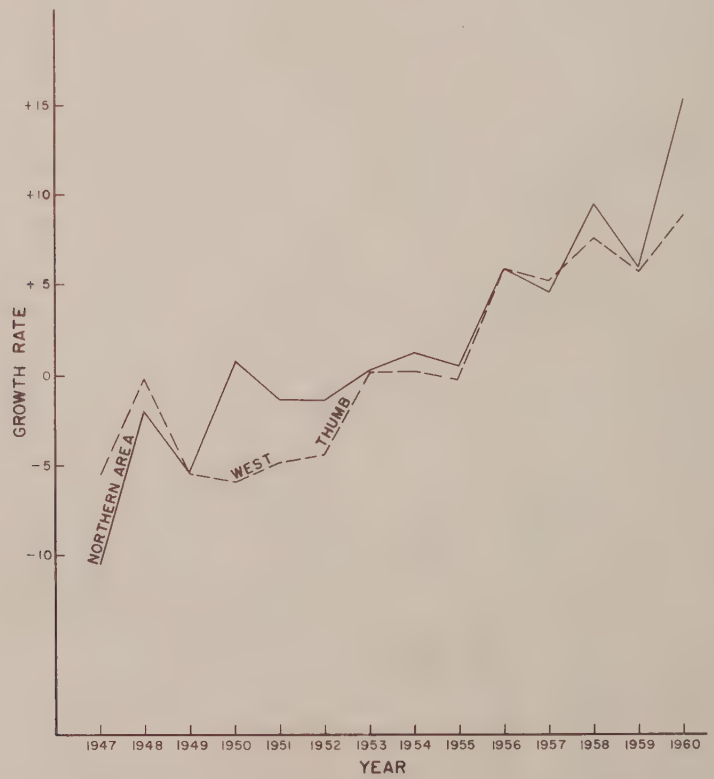

FIGURE 4.—Percentage deviation from mean growth rate by year for northern area (solid line) and West Thumb (broken line), 1947 to 1960.

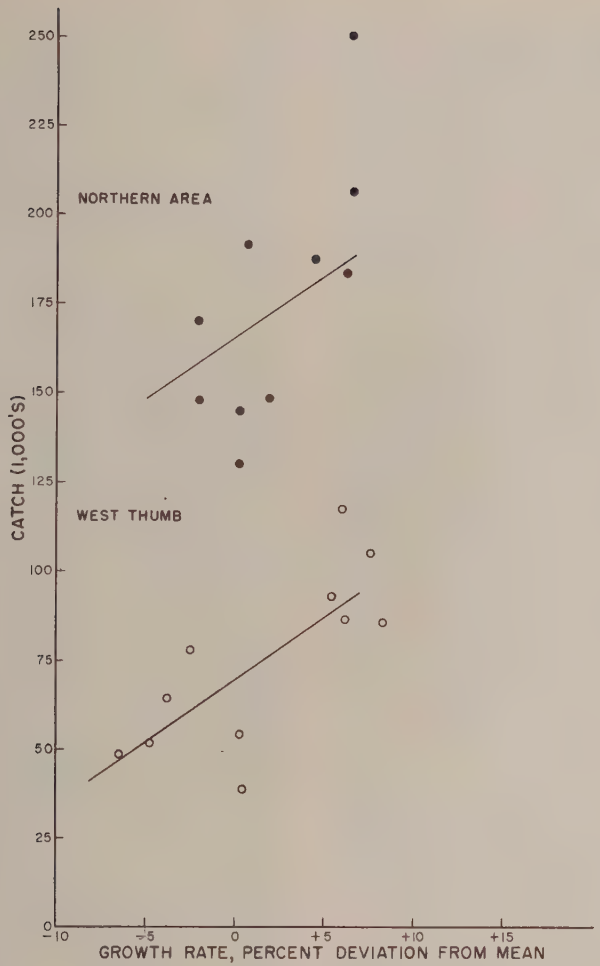

FIGURE 5.—Growth of fish from West Thumb and northern area compared with catch for same year. Growth rates expressed as percentage deviation from mean of all age groups. Regression lines calculated to show trend.

Availability by length has been rather constant in this fishery. There has been no evidence that fish are maturing at an earlier age. Earlier maturity may become more evident in the future since fish of age groups II and III showed an increased growth rate in 1958, 1959, and 1960. Later in this report we show that the increase in growth rate of these age groups did not occur until overfishing commenced, which suggests that exploitation of prespawners should not be excessive if the stock is managed at equilibrium yield.

It may be expected that the increase in growth rate in recent years would be accompanied by an increase in condition factor (K). Condition factor has been used occasionally as an index of stock density on the assumption that reduced density would allow increased growth in weight as well as length. MacGregor (1959) found that condition factor was a valuable measure of population size of the

Pacific sardine. Condition of Yellowstone Lake cutthroat varied so much with stage of maturity, sex, size, and time of year that no segment of the fishable stock or the catch could be measured adequately to determine variations in condition factor.

Spawning runs

The size of the spawning runs in six tributary streams has been measured each year since 1945, except for a few years. The sampled streams are in different areas of the lake (see fig. 1), but their relation to the total spawning population is unknown. Ball and Cope (1961) found 14 major and 26 minor tributaries to Yellowstone Lake, and the sampled streams are all major by their classification. Contributions from small tributaries to the lake stock undoubtedly fluctuate greatly because wave action often dams the mouths of small streams with sand spits, and stream flow percolates through the gravel. Both postspawners and immatures are trapped behind the sand spits as they attempt to move toward the lake, and mortality is undoubtedly high. Sand spits never block the mouths of the major tributaries, although a large lagoon at the mouth of Arnica Creek frequently becomes cut off from the lake during the late summer in low-water years.

The location of the sampled streams subjects the postspawners to different rates of fishing pressure. Ball and Cope (1961) found that the average fishing mortalities in the 1949–53 period for the five streams were as follows: Pelican, 12.2 percent; Arnica, 9.3 percent; Clear, 9.4 percent (1953 only); Grouse, 3.7 percent; and Chipmunk, 5.2 percent. Evidence presented earlier suggests that the true fishing mortalities are higher than the percentages shown above, but the ratios among streams are probably correct.

Some characteristics of all spawning runs are as follows: (1) Homing of adults is strong, since 96.8 percent of the returns from a tagged sample of 17,836 fish were later recovered in the same stream as tagged (Ball, 1955); (2) homing of immatures is present, since 19.9 percent of 644 fin-clipped trout returned to the same stream as marked and none to any other sampled stream; (3) differences in time of migration by stream or season are related to water levels and temperatures (Cope, 1956); (4) each stream has a consistent annual pattern of spawning migration; and (5) age groups IV and V include most spawners although III's were important in some years (table 10).

Reliable data on the amount of fishing pressure exerted on prespawners and their movements in the lake are not available.

TABLE 10.—*Age composition of spawning runs in five tributaries of Yellowstone Lake, by years, 1949 to 1961*

Stream and year	Percent in age group—				
	III	IV	V	VI	VII
Pelican Creek:					
1949	3.4	79.4	16.6	0.6	0
1950	4.6	59.6	30.3	4.3	1.2
1951	2.5	55.4	38.1	4.0	0
1952	14.3	60.3	22.0	2.7	.7
1953	8.3	62.8	25.6	2.6	.6
1954	5.6	55.6	35.2	3.7	0
1955	6.6	57.9	32.0	3.4	.1
1956	6.2	60.6	31.7	1.5	0
1957	2.9	73.2	23.6	.3	0
1958	3.0	65.0	32.0	0	0
1959	2.1	71.2	23.3	3.4	0
1960	4.7	60.6	31.8	2.5	.3
1961	7.1	54.5	36.9	1.5	0
Arnica Creek:					
1951	11.4	45.3	32.2	10.4	.7
1952	16.6	49.3	32.5	1.6	0
1953	11.1	58.9	29.0	1.0	0
1954	11.5	37.5	47.5	3.5	0
1955	8.4	61.5	28.8	1.3	0
1956	9.8	55.8	31.9	2.5	0
1957	2.9	41.0	53.7	2.4	0
1958	1.9	30.7	59.9	6.5	1.0
1959	4.3	62.6	32.2	.9	0
1960	17.5	66.1	13.4	3.0	0
1961	9.2	66.7	23.2	.9	0
Chipmunk Creek:					
1949	1.8	41.0	47.7	6.3	3.2
1950	.4	38.0	48.6	12.0	1.0
1951	.2	39.2	45.8	12.9	1.9
1952	1.9	46.1	38.6	12.2	1.2
1953	.7	37.0	36.5	23.2	2.5
1954	.9	31.8	40.9	20.6	5.7
1955	2.7	66.8	24.9	4.8	.8
1956	2.5	44.1	40.1	11.9	1.4
1957	.4	43.6	48.6	6.3	1.1
1958	.2	36.4	56.0	6.9	.5
1959	1.0	34.8	48.4	5.8	0
1960	.5	47.7	48.8	2.7	.3
1961	1.3	44.8	49.9	3.2	.8
Grouse Creek:					
1952	0	55.2	43.4	1.4	0
1953	4.0	63.4	28.9	3.3	0
1954	0	24.4	59.4	13.5	2.7
1955	0	50.6	42.8	6.6	0
Clear Creek:					
1953	0	60.7	35.2	4.1	0
1954	0	58.3	33.3	7.8	.6
1955	5.3	75.9	18.8	0	0

We expect, from data on homing, that prespawners produced in a stream near an area of heavy fishing pressure will be subjected to a greater rate of exploitation than those produced from a stream in an area of low fishing pressure. Accordingly, the prespawners from Pelican Creek are subjected to greater fishing pressure than those from Chipmunk Creek. It is probable that the differences in fishing mortalities of postspawners for the five sampled streams presented above could be applied, in general, to prespawners. Characteristics of each spawning stream were described by Ball and Cope (1961), and the differences in the spawning stocks among streams are discussed below.

Arnica Creek

Arnica Creek, one of the smallest streams studied, had spawning runs ranging from 1,755 in 1959 to 6,200 in 1954 (table 11). Spawning migrations were spread over a period of about 30 days, and large runs showed migration patterns similar to those of small runs. Age groups IV and V were most important, but III's were common from 1951 to 1954 (table 10). Bulkley (1961) found that strong year classes were produced in 1949, 1951, and 1953, and weak year classes in 1948 and 1955. No regular cyclical patterns of year-class strength were noted. A clear understanding of Arnica Creek year-class strength is obscured because the large lagoon at the mouth is occasionally cut off from the main lake in August; this factor probably influences the survival rate of immatures leaving the stream. In 1960 and 1961 it was observed that the outlet of Arnica lagoon was cut off from the lake in the spring, and this prevented spawners that had wintered in the lake from entering Arnica Creek until after a significant part of the spawning run had migrated upstream. The early part of the run must have been composed of spawners that wintered in the lagoon. This lagoon has probably been cut off in previous years and has influenced mortality rates of both adults and immatures.

It is not possible to relate the effects of increased catch to Arnica Creek spawning runs precisely, but the low runs in 1959, 1960, and 1961 could be attributed only to the heavy catches in West Thumb. Effects of fishing were strong in the 1960 run as shown by the few fish of age group V present.

TABLE 11.—*Annual counts of spawners in six tributaries of Yellowstone Lake, 1945 to 1961*

Year	Pelican Creek	Clear Creek	Chipmunk Creek	Grouse Creek	Cub Creek	Arnica Creek
1945	22,297	13,123	13,589	13,264	6,864	-------
1946	14,588	16,429	22,496	6,171	11,027	-------
1947	19,613	23,211	11,107	8,158	11,344	-------
1949	32,431	7,274	13,580	11,790	-------	-------
1950	15,076	10,459	12,255	9,635	2,179	3,881
1951	9,423	16,879	12,585	12,188	2,676	4,755
1952	7,953	10,269	9,989	6,949	2,056	3,523
1953	12,413	10,323	7,836	7,441	3,848	4,524
1954	10,340	3,161	5,371	3,756	3,446	6,200
1955	12,400	7,929	3,880	-------	2,558	4,700
1956	-------	-------	-------	-------	-------	3,912
1957	17,500	8,398	9,605	-------	2,976	3,812
1958	7,259	9,355	8,922	13,462	1,747	4,041
1959	22,198	3,353	6,225	7,330	7,257	1,755
1960	3,363	-------	3,456	10,570	-------	2,346
1961	15,568	8,119	4,382	4,235	5,087	2,090

Pelican Creek

Pelican Creek has the largest spawning run of the streams sampled, and its postspawners are subjected to the greatest fishing pressure. The number of spawners ranged from 3,363 in 1960 to 32,431 in 1949. Strong year classes were produced in 1949, 1953, 1955, and 1958. Weak year classes were produced in 1948, 1952, and 1956. Bulkley and Benson (1962) found a high positive correlation between strong year classes in Pelican Creek and low water levels, and developed a formula for prediction of year-class strength based on water levels during the period of spawning and incubation. With the great importance of stream water levels to year-class strength, a close relation between size of escapement and year-class strength cannot be expected.

The minimum escapement necessary for Pelican Creek varies annually with environmental conditions, which emphasizes

the danger of maintaining escapement at a low level. A small escapement may be able to produce an average year class if environmental conditions are favorable, whereas the same amount of escapement in a year of unfavorable conditions may produce practically no progeny. To assure adequate reproduction, Pelican Creek spawning runs should not go below 7,000 fish, and should be above 10,000 fish. The small 1960 spawning run of 3,363 fish was attributed to the very heavy catch in 1959 and is considered to be much too low to assure the production of a strong year class.

Clear and Cub Creeks

The spawning migrations in Clear and Cub Creeks are delayed more than those in the other streams studied because of low stream water temperatures. This condition allows heavier exploitation of prespawners during the first few weeks of each angling season because the fish are concentrated in the lake around the stream outlets.

There are not enough data to relate catch to size of spawning runs accurately for these streams. The runs in Clear Creek have been low since 1952 (table 11). The Cub Creek spawning runs were low from 1950 to 1958, but a large number of trout were counted in 1959. The trend in both of these streams has been downward, and it is undoubtedly related to increased catch.

Chipmunk and Grouse Creeks

Chipmunk and Grouse Creeks are in the south end of the lake where fishing pressure is light, although most recoveries of tagged postspawners were in West Thumb, with a few in the northern area. Both these streams have an unusually high percentage of fish of age group V in each spawning run (table 10), and Bulkley (1961) suggested that recruitment into spawning runs may not be completed until age V. Thus, any increase in the catch of age group IV fish (see fig. 3) would influence these spawning runs to a greater degree than the other study streams. The trend in Chipmunk has been downward since 1952 (table 11). Bulkley and Benson (1962) related year-class strength in Chipmunk to various environmental factors. Good production can be expected if water levels are low and relatively stable during the incubation period, and if spawner numbers are adequate. An escapement of 4,600 fish appears to be suitable.

Weak year classes are produced in years when lake water levels are high or fluctuate widely during June and July, even when spawning runs are large. The low spawning run in 1960 resulted from an overexploited 1955 year class and a weak 1956 year class. The 1955 year class was abundant because environmental conditions were ideal for high production in 1955 and the escapement was not too low, but the large catch of age group IV fish in 1959 caused overexploitation of this year class before many of the fish reached maturity. Grouse Creek data are scanty, and no definite conclusions can be made.

Mortality rates

Mortality rates for Yellowstone Lake cutthroat have been determined from tagging studies and from catch curves. Ball and Cope (1961) calculated mortality rates from returns of tagged spawners in Yellowstone Lake from 1949 to 1953. Their figures on fishing mortality rates of postspawners averaged 8.2 percent and ranged from 2.2 to 15.2 percent. Their data indicate that most of the catch must come from prespawners. They did not consider the differential mortality between tagged and untagged fish in the lake, as explained earlier, and the average of 8.2 percent fishing mortality was probably low.

Catch curves are obtained by plotting the $\log_{10}$ frequency of occurrence of fish in the catch against age. Total instantaneous mortality rate can then be obtained by determining the natural loga-

rithm of the difference in number of fish caught from two consecutive age groups. A catch curve from 1 year's data is only valid for computing mortality and survival rates if year-class strength remains relatively stable from year to year. This assumption could not be met in Yellowstone Lake, as wide fluctuations in year-class strength occur. Catch curves of individual year classes are difficult to interpret because contributions of a year class to the catch at different ages is influenced both by the size of the catch in different years and by strength of neighboring year classes. We have used year-class catch curves to calculate total instantaneous mortality rates. These should not be interpreted as actual values, as both catch and year-class strength varied annually in the fishery. They have been included only to illustrate the changes which occurred between the times the 1946 and 1956 year classes entered the catch.

Mortality rates of fish in age groups IV and V were computed from catch data for West Thumb and the northern area presented in appendix E. Mortalities of age groups II and III were not calculated owing to incomplete recruitment of these age groups to the fishery. The catch-curve data and resultant mortality rates for the northern area are a more reliable index of stock conditions than those from West Thumb. The West Thumb stock is composed of fish from many spawning streams which differ considerably from each other in year-class strength and in seasonal recruitment to the fishery. Hence in any given year the catch may have a different proportion of fish from a particular stream than in the previous or ensuing years. The northern area stock is derived principally from the Yellowstone River and Pelican Creek, which are similar in relative year-class strength and in seasonal recruitment to the fishery.

For the northern area, mortality rates of age group IV fish were grouped rather close together and remained below 0.5 until the catch exceeded 200,000 fish in 1958 (tables 3, 12). Mortalities at this age for later year classes varied from 0.845 to 1.637. Mortality rates of age group V remained very close to 2.0 prior to the 1952 year class but with much less fluctuation than age group IV. Rate for the 1953 year class jumped to 5.812 with the 1958 catch and remained high for the 1954 year class also.

TABLE 12.—*Instantaneous total mortality in cutthroat trout of age groups IV and V from northern area and from West Thumb, by year classes, 1946 to 1956*

Year class	Northern area		West Thumb	
	Age IV	Age V	Age IV	Age V
1946	0.017	2.228	0.059	1.574
1947	.233	1.618	.411	2.044
1948	.381	1.948	1.139	1.960
1949	(1)	1.251	.488	1.667
1950	(1)	2.332	.463	2.845
1951	(1)	2.798	.470	2.299
1952	.310	1.886	.177	2.990
1953	.184	5.812	.183	5.741
1954	.845	4.096	1.432	2.314
1955	1.637	(2)	2.123	4.589
1956	1.402		1.385	

[1] Mortality not calculated owing to recognized sampling error. More V's than IV's were sampled from the catch.
[2] No age group VI fish in sample of 1961 catch.

In West Thumb, total instantaneous mortality of age group IV did not exceed 0.5, with the exception of the 1948 year class, until the catch exceeded 100,000 fish in 1958. From 1958 to 1960 the mortality rate for age group IV remained well above 1.0 even though the West Thumb catch dipped to 85,953 fish in 1960. Mortality rates for age group V fish climbed slowly and somewhat erratically until that of the 1953 year class, which was almost double the mortality of the previous year class with a value of 5.741. The 1954 year class was not adversely influenced according to these data, but the 1955 year class again experienced high mortality at age V.

There is a possibility that natural mortality could have varied enough to influence the total instantaneous mortality rate, which comprises both natural and fishing mortality. The major source of

natural mortality for the catchable-sized stock is that associated with spawning. Ball and Cope (1961) determined stream mortality for five spawning streams through tagging from 1949 to 1953. Their estimates from all streams ranged from 23.0 to 94.9 percent and averaged 48.1 percent. This range gives the impression that spawning mortality varies greatly among streams and among years. A close examination of the tag returns shows that the large variations among years occurred only when tag returns were low, and several sources of error could have influenced the percentages, as mentioned by the authors. The data from 1951 to 1953 for Arnica and Pelican Creeks, when the percentages of tag returns were the highest, did not show these extreme variations since mortality rates ranged only 15 percent for Arnica and 9 percent for Pelican. The Arnica spawning mortality in 1953 is known to be accurate because it agreed closely with a direct count. Thus, the hypothesis that spawning mortality in any single stream is fairly constant agrees closely with the above mortality data when only the most reliable tagging data are considered. The high total mortality rates for the 1953 to 1955 year classes must have been due to increased catch since no other recognized variable was present during the years when these year classes were being exploited. The consistently low instantaneous mortality rates among year classes 1946 to 1952 support the conclusion that increased fishing mortality caused the changes observed in the later year classes.

Year-class strength of catch

Bulkley (1961) analyzed the relative year-class strength of the northern area and West Thumb catches, utilizing the method of el-Zarka, (1959) which is based upon the percentages of all age groups from each year class that enter the catch. A summary of the data used for computing relative year-class strength from 1944 to 1957 is presented in appendix D. In the northern area, strong year classes occurred in 1945, 1949, 1953, and 1957, or at 4-year intervals (fig. 6). In West Thumb, strong year classes were produced in 1947, 1952, 1953, 1955, and 1957. A large annual variation in year-class strength in both areas was especially noticeable. The West Thumb stock varied more irregularly than the northern area because it is derived from many spawning streams which vary independently in year-class strength from year to year.

There is no indication that the increased catch from 1950 to 1961 adversely influenced year-class strength, although it definitely reduced the size of spawning runs entering most of the study streams. The 1960 spawning run of 3,363 fish in Pelican Creek was probably closest to the point where escapement became the limiting factor in production for that stream. Additional data will be needed for each spawning stream to ascertain the level of escapement at which environmental conditions are no longer the major limiting factor in year-class production, although this relation obviously varies annually in the same stream as well as among streams.

The increased catch introduced a bias into the estimates of relative strength of the 1954 and 1955 year classes. This bias appears in the el-Zarka method whenever the catch is sufficient to reduce the size of older age groups in the population and shifts to younger age groups. The 1954 year class is probably represented in figure 6 as being slightly weaker than it actually was, and the 1955 year class is definitely represented as being too weak.

MAXIMUM EQUILIBRIUM YIELD

Method

Maximum equilibrium yield has been defined by Ricker (1958a) as the largest average catch which can continuously be taken from a stock under current environmental conditions. Overfishing com-

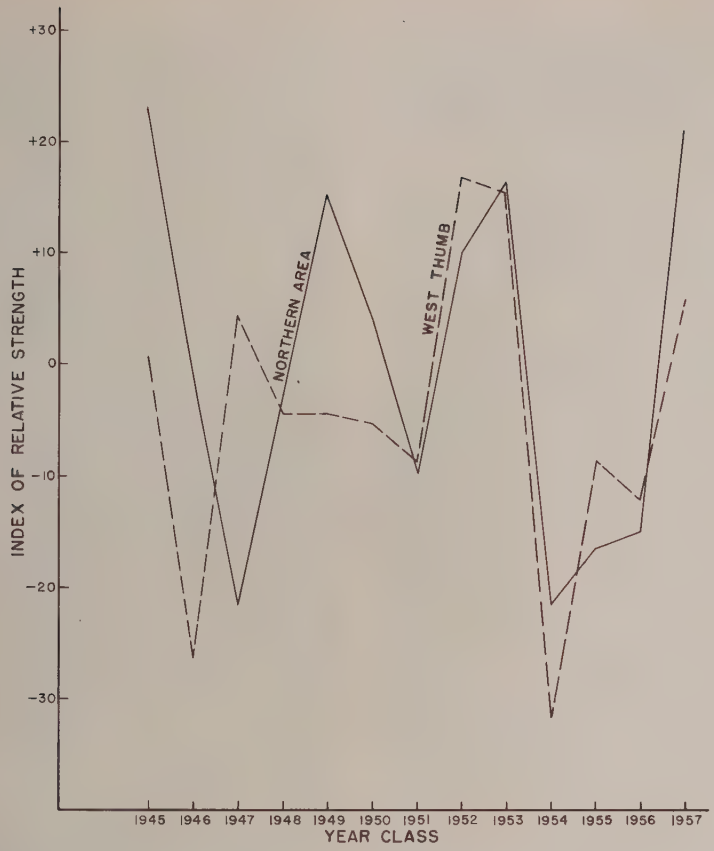

FIGURE 6.—Relative year-class strength based on contributions to the catch of all age groups for northern area (solid line) and West Thumb (broken line), 1945 to 1957.

mences whenever the catch surpasses equilibrium yield. For Yellowstone Lake, yield is considered numerically because it can be administered most easily on this basis. We have defined overfishing in this stock as the removal of so many fish that the following conditions exist: (1) Growth rate remains high, but the mean size and mean age of the catch decrease to a greater extent than can be attributed to variations in year-class strength; and (2) the spawning stock is excessively reduced by the catch. This definition of overfishing follows the more generalized definition of Rounsefell and Everhart (1954) with the addition of methods for its recognition in the Yellowstone stock.

Miller (1949) studied commercially exploited whitefish populations in Alberta under various rates of exploitation and observed overexploitation of the stock. He was able to determine the conditions that preceded and ultimately caused overfishing. Overfishing resulted from overexploitation of the old age groups which caused an overabundance and slow growth of young age groups. In his words, "Overfishing begins when decreasing average age overtakes increasing growth rate and before decreased yields are evident". In that fishery overfishing was evident (but not recognized) about 2 years before collapse.

Nikolsky (1953) summarized some indices for estimating the best rate of exploitation of fish stocks and considered maximum or optimum rate of growth for the species in the environment a desirable goal.

Ricker's (1958a) explanation of the relations of reproduction curves and yield has been useful. Several ideas of Beverton and Holt (1957) were considered, although their methods could not be directly applied. Graham's (1935) ideas of surplus stock and yield were also helpful. The use of a mathematical model to express the stock changes was attempted, but insufficient data were available to construct a model without a large inherent error. Several limitations of applying mathematical models to sport fishery stocks were aptly discussed by Watt (1959). He analyzed a smallmouth bass population by several of the accepted methods and concluded that, "The form of equations for use in predicting and managing complex biological phenomena must be dictated by the ultimate reality for the phenomenon, the data themselves, not by *a priori* deductions."

Our method for estimating yield consists in establishing three stages of exploitation from our knowledge of changes that have occurred in the stock. Equilibrium yield was estimated by fitting catch data to these stages. The method requires long-term data and provides only a rough estimate of yield, but it does not require the voluminous data required for the development of an accurate mathematical model (see Watt, 1959, p. 391). Several of the criteria used in this method can be applied to many sport fishery populations.

During the first stage increased catch reduces stock density, and growth rate increases to its optimum level for the environment. Mean length of the catch remains stable, but mean age decreases. Utilization of fish foods becomes more efficient. Total instantaneous mortality rates of age group IV trout, as determined from year-class catch curves, do not exceed 0.5. Adequate spawning stocks are maintained. The most efficient production for angling purposes is attained at the maximum catch of this stage and is the maximum equilibrium yield.

In the second stage overfishing commences. Decreasing mean age of the catch overtakes increasing growth rate to a greater extent than can be attributed to variations in year-class strength. Lower mean age of the catch and lower mean lengths result. Fish of age groups II and III enter the catch prior to the time they normally do, and the number of age group IV's greatly exceeds the number of V's. The number of fish caught will remain similar to the first stage for a time, but continued removal of older age groups will lower the total catch near the end of the stage. Total instantaneous mortality rates of age group IV trout, as determined by year-class catch curves, exceed 0.5. Older groups are exploited heavily enough to reduce spawning stocks significantly, and spawning runs show a lower mean age.

The third stage will be reached when the catch removes enough of the sexually mature fish to prevent full utilization of the suitable spawning and rearing sites. Production of immatures will be reduced. Recovery from this stage will require several years or until the necessary numbers of spawners to utilize the available spawning facilities are restored to the stock.

The estimation of yield by these stages follows Ricker's use of reproduction curves to calculate yield but also considers growth rate, lengths, and age distribution of the catch. It was not possible to calculate a reproduction curve for the lake stock because there are not sufficient data to relate size of escapement to recruitment. Data from Pelican Creek show that water levels alone accounted for 94 percent of the variation in year-class strength, and

Bulkley and Benson (1962) concluded that environmental factors had such a strong influence on production that an adequate escapement could not produce a strong year class unless water conditions were favorable. As suggested earlier, the spawning run in 1960 for Pelican Creek is too low for adequate seeding, but the minimum level of escapement necessary to produce a good year class varies with environmental conditions. There is, obviously, a low limit of desirable escapement for each stream which will insure some recruitment even with adverse stream conditions. The low escapement in several streams that resulted from the increased catch during 1958 and 1959 is not a safe condition to insure adequate annual recruitment.

Calculation of estimated equilibrium yield and analyses of changes in the Yellowstone stock in relation to the above stages of exploitation are discussed below.

Calculation of yield

Northern area and West Thumb stocks will be discussed separately, and a yield for the entire lake will be considered later. Changes in stock condition as related to total catch, growth rate, mean age and length, and annual catch curves are summarized in figure 7. Annual catch curves illustrate the degree of exploitation when analyzed in conjunction with the other data, including year-class strength.

In the northern area catch, all fluctuations in mean age and length before 1958 can be attributed to differences in year-class strength and to the increase in growth rate. As explained earlier, optimum growth rate was reached in 1956. The drop in mean length and age in 1952 was due to a large number of fish of age group III in the catch from the strong 1949 year class. The increase in mean length from 1955 to 1958 was due to the heavy catch of age groups IV and V and to the increase in growth rate. Mean age changed little from 1955 to 1957, but both mean age and mean length have dropped consistently from 1958 to 1961.

Catch curves before 1959 were flat on top because age groups IV and V were caught in approximately equal numbers. Some fluctuations among age groups III, IV, and V were evident, owing to variations in year-class strength, but the same general pattern was maintained. The 1957 catch curve was peaked because fish of age group IV from the strong 1953 year class were caught in large numbers. The 1958 catch curve does not look much different from those of previous years, but both the IV's from the weak 1954 year class and the V's from the strong 1953 year class were exploited heavily, so that few V's from the 1954 class and VI's from the 1953 year class were caught in 1959. Continued heavy catches in 1959 and 1960 of the IV's and V's resulted in catch curves for 1960 and 1961 that showed exceptionally heavy exploitation. We consider an annual catch curve with a steep right slope after age IV to be indicative of heavy exploitation during the previous year as long as the steepness is not the result of variation in year-class strength. In 1959, 1960, and 1961 there were many age group III's in the catch. This exploitation caused a low mean age in 1959, 1960, and 1961, and a drop in mean lengths in 1960 and 1961. The lower mean ages and lengths in 1960 and 1961 were not caused by year-class strength but by overexploitation of the 1955 and 1956 year classes in 1959 and heavy exploitation of the 1957 and 1958 year classes in 1960. The excessive exploitation reduced the 1960 spawning run in Pelican Creek and caused overfishing. Overfishing commenced somewhere between the 1957 catch of 187,462 and the 1958 catch of 219,036.

In the West Thumb stock, age groups III, IV, and V were more equally represented in the annual catch curves before

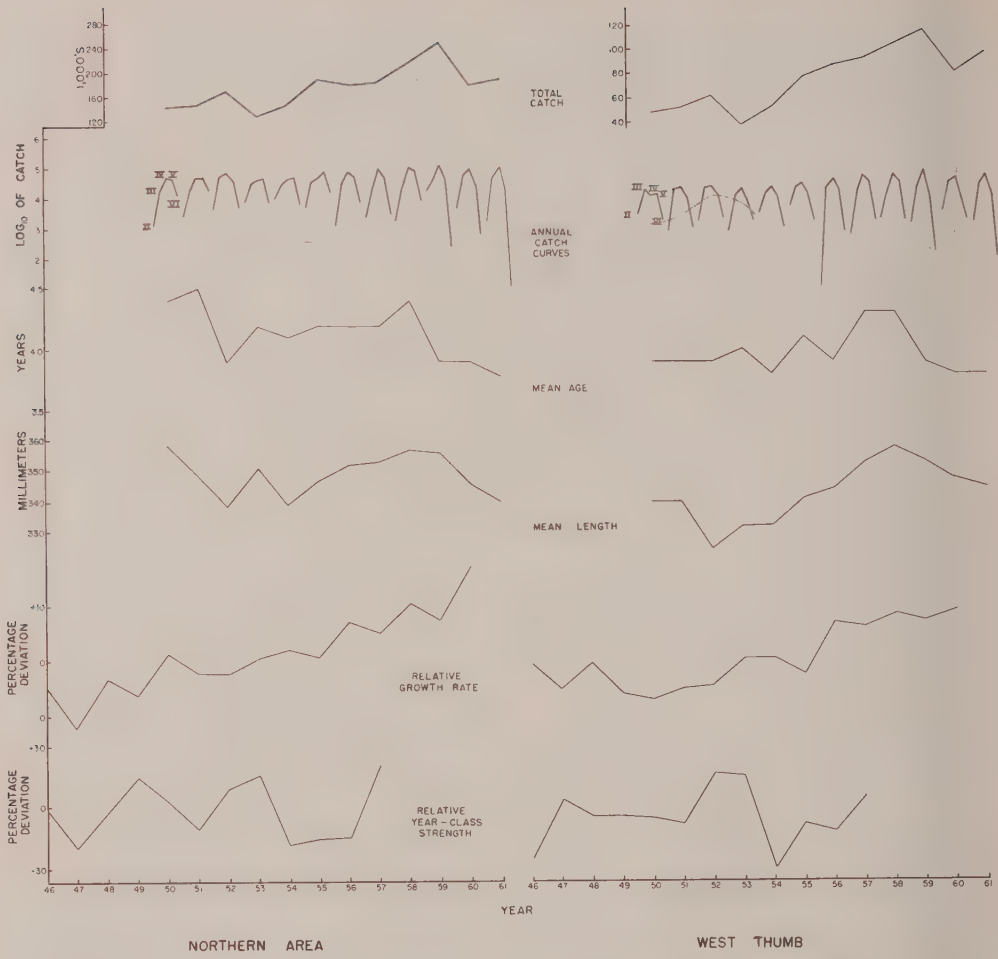

FIGURE 7.—Data from northern area and West Thumb collected from 1950 to 1961, including relative year-class strength, total catch, relative growth rate, mean lengths, mean age, and annual catch curves.

1958 because the fishery is not heavily concentrated on a spawing population. The changes in mean lengths and mean ages before 1958 can all be explained by variation in year-class strength which altered ratios of age groups in the catch. Since 1958 the mean length and mean age of the catch have dropped each year as the result of heavy exploitation. Low mean lengths in 1952, 1953, and 1954 were due to a large number of III's and few V's in the catch. The increase in mean length from 1954 to 1958 was due to the large number of IV's and V's in the catch and to increased growth rate. The mean age dropped in 1956 owing to the large number of III's from the strong 1953 year class. In 1958 the V's from the 1953 year class and IV's from the 1954 year class were heavily exploited, and there was an abrupt drop in the catch of these year classes in 1959. The heavy 1959 catch was concentrated on the IV's from the 1955 year class, and there were few V's caught from this year class in 1960. As in the northern area, West

Thumb annual catch curves had a steep slope from age group IV to age group VI after the 1958 catch. Both the Arnica Creek and Chipmunk Creek spawning runs were reduced by the 1959 and 1960 catch. The West Thumb stock was overfished in 1958 with a catch of 105,000 fish.

Catches and stages of exploitation of of the lake population are summarized as follows:

Year	Catch in—		Stage of exploitation
	Northern area	West Thumb	
1957	187,462	92,174	Stage one, no overexploitation.
1958	219,036	105,155	Heavy exploitation of IV's of 1954 year class and V's of the 1953 year class caused stock to enter stage two.
1959	250,310	117,171	Heavy exploitation of IV's from 1955 year class and V's from 1954 year class. Spawning runs in 1960 had fewer V's than expected. Mean length and age lower than could be attributed to year-class strength.
1960	181,588	85,953	Mean age and length continue to drop owing to heavier than normal catch of III's and few V's and VI's. Stock in stage two with some evidence of stage three from spawning runs as a result of the large 1959 catch.
1961	192,211	97,114	Mean age and length continue to drop owing to heavy catch of III's and IV's and few VI's. Stock in stage two, but some evidence of recovery in Pelican Creek spawning runs due to lighter catch in 1960.

Overfishing in both the northern area and West Thumb commenced at an unknown catch level in 1958 between the 1957 and the 1958 catch. We know that the year classes in the 1957 catch were stronger than those in the 1958 catch, but we cannot determine when the equilibrium was surpassed in 1958. Our best estimate is the average between the 1957 and 1958 catch, or about 203,000 trout for the northern area and 98,000 trout for the West Thumb area. With the addition of the southern area, the maximum equilibrium yield for the lake is estimated to be 325,000 fish with the present distribution of fishing pressure.

Since each annual catch curve may have six different year classes of various strengths, maximum equilibrium yield can be expected to vary from about 290,000 to 340,000 fish. The lowest equilibrium yield will occur when age groups III, IV, and V, the principal age groups in the catch, come from three consecutive weak year classes, and the highest yield will be possible when these three age groups come from three strong year classes. Since year-class strength varies so greatly among different streams, it is doubtful whether either extreme could occur.

The catch data in appendix E give some information on the approximate numbers of trout that were caught from year classes of different strengths by age group. It is realized that this information is susceptible to large error since differences in total catch and strength of the neighboring year classes have materially influenced these figures. It would require many years of relatively constant catch to determine the exact influence of year-class strength on the entry of age groups into the catch and resultant differences in natural mortality. From the available catch-curve data the hypothetical number of fish, in thousands, that could be caught in the northern area, without overfishing, has been estimated for weak, average, and strong year classes (table 13). Each annual catch curve contains five or more year classes of various strengths, and the shape of the annual catch curves will oscillate, even with an equilibrium catch. Overfishing can be recognized only if strength of each year class in the catch curve is considered.

TABLE 13.—*Hypothetical equilibrium yields of cutthroat trout for northern area from weak, average, and strong year classes*

[In thousands of fish]

Age group	Yield if year class is—		
	Weak	Average	Strong
II	2	5	8
III	25	30	35
IV	80	90	100
V	60	70	80
VI	6	8	10
Total	173	203	233

These overfishing conditions described for Yellowstone Lake agree quite closely with those described by Russell (1942), who discussed the overexploitation of ground fish in the North Sea. In his words,

> We have already seen in a general way what happens in a well-fished stock after the accumulation of old slow-growing fish has been swept away. The density (in terms of weight) falls gradually with increased fishing, the percentage of large fish diminishes, and finally the total yield falls, and we get overfishing.

MANAGEMENT

Regulations

Knowledge of the approximate equilibrium yield of a fish population is of little value for management unless the fishery can be regulated to attain and maintain that yield. In some populations, decreased density acts as a natural brake on stock depletion by reducing availability. Angling automatically becomes less efficient, and catch per unit of effort decreases. On Yellowstone Lake the catch per man-hour did not change much even when density of the stock was reduced and the stock overexploited, because the fishery was centered over spawning concentrations and more efficient angling gear came into general use. With a high catch per hour, a decline in fishing interest cannot be expected to slow down depletion of the stock. Additional regulations must be adopted to restrict the catch to equilibrium yield. Several possible regulations are considered here with the following questions in mind: (1) Is this regulation practical for Yellowstone Lake? (2) Will it be effective in reducing the catch without destroying the incentive to fish? (3) What will be its influence, and can its effect be predicted?

Control by quotas

An attempt can be made to manage a fishery on equilibrium yield by use of an annually adjusted number of fishing trips, or a "quota" system. Such a system will always be difficult to apply to a sport fishery because angling success and pressure are too unpredictable. For Yellowstone Lake, we do have adequate background biological data for reliable prediction within reasonable limits, and it would be possible to establish the necessary number of fishing trips to attain a desired yield; but other factors make a quota system based on fishing trips impractical for Yellowstone Lake, as well as for most sport fisheries on public waters. There would be too many administrative problems in deciding who may fish, and when, to consider such a method. Ricker (1958b) stated that the objectives of a quota system can be obtained by other methods of regulation. Catch goals by numbers or weight in commercially exploited stocks are often too difficult to administer, and regulation by season, area of fishing, and the like, are frequently used to attain equilibrium yield. Some of these methods are applicable to the Yellowstone Lake fishery.

Shortening of fishing season

Shortening the fishing season is another method to be considered for restricting the catch. The present June 15–October 15 fishing season on Yellowstone Lake is already short, and fishing pressure is very light after the Labor Day weekend (around September 5) when most of the tourist accommodations are closed. Fishing is essentially limited to a 2¾-month period. As shown in table 5, 60 percent of the catch is made before August 1. Closure of the season at a date earlier than October 15 would not be effective for preventing overexploitation unless the season closed August 15 or earlier. This early closing date would stop fishing when the fish are in the best condition and furnish the most sport.

A later opening day such as July 1 would reduce the catch enough to be of some biological value. The fishing from June 15 to June 30 is concentrated on spawning fish, and some of these fish would disperse enough, before a July 1

opening, to lessen their chances for capture. The present opening date protects much of the spawning, but a July 1 opening date on the lake and river would have considerable value, especially in years of low escapement or delayed spawning. In 1960, 33.4 percent of the June 15–30 catch landed at Fishing Bridge dock consisted of ripe or partially spent fish. It is not possible to regulate the opening of any fishery precisely enough by chronological time to allow all fish to spawn before capture because "biological time" varies too much among years. Even vast amounts of past data on timing of spawning migrations may not give the necessary information for effectively regulating the catch during any specific year. A later opening would have an undesirable economic influence on the boat concessionaires because it would mean no fishing when fish are most available. The present fishing season should be retained until other methods of reducing the catch have been tried.

Minimum size limits

Size limits are used to protect breeding stocks and/or to adjust the size distribution of the catch to attain the most desirable yield (Allen, 1954). For Yellowstone Lake a minimum size of 12 inches (305 mm.) is recommended. The effects of this size limit on the catch and on various age groups from 1950 to 1961 are shown in table 14. Up to 1955, the catch would theoretically have been reduced by an average of 12.7 percent with this size limit. Since 1956, when the growth rate reached its optimum, this size limit would have reduced the total catch by a maximum of 13.9 percent and an average of 9.5 percent. Obviously the actual reductions on size of catch would not approach these percentages, as many fishermen would continue fishing until they did catch fish large enough to keep.

With the present growth rate, a 12-inch size limit would essentially eliminate age group II from the catch, reduce the catch of age group III by about one-half, and affect virtually no older age groups. It would allow higher survival of prespawners, but it would not have a great influence on the average size of the fish in the creel (see table 6). A lower size limit would have little value because of the low availability of small fish. A larger size limit of 13 inches would almost eliminate age group III from the catch, which is not considered necessary at this time. The increase in the catch of age groups II and III in 1959 and 1960 suggested that some

TABLE 14.—*Percentage of fish less than 12 inches long in total catches and in age groups of catches from the northern area and from West Thumb, by years, 1950 to 1961*

[All fish of age group V and older are above 12 inches]

Year	Percent in total catch from—			Percent in age group—					
				II		III		IV	
	Northern area	West Thumb	Northern area and West Thumb	From northern area	From West Thumb	From northern area	From West Thumb	From northern area	From West Thumb
1950	5.7	16.1	8.3	100.0	100.0	50.0	74.2	1.1	2.1
1951	13.3	15.0	13.7	100.0	100.0	63.3	53.0	3.2	3.7
1952	13.3	15.8	13.9	92.6	90.0	42.2	56.5	0	5.8
1953	13.0	12.0	12.8	95.0	90.9	53.5	45.0	.9	3.3
1954	12.3	18.8	14.0	95.4	96.6	41.7	50.0	0	3.3
1955	14.1	10.9	13.2	90.0	84.2	61.6	30.4	2.5	.6
1956	6.5	7.3	6.8	100.0	----------	33.3	33.3	3.1	0
1957	4.8	8.4	6.0	100.0	100.0	49.4	67.5	0	0
1958	8.9	7.6	8.5	85.9	95.0	47.5	47.2	0	1.3
1959	8.8	11.3	9.6	69.6	100.0	46.3	40.3	0	4.2
1960	9.3	9.3	9.3	100.0	100.0	49.1	50.8	0	1.6
1961	15.4	12.6	13.9	100.0	100.0	52.0	39.9	1.0	1.5

measure is necessary to reduce the exploitation of these age groups. The low number of spawners of age group IV in 1960 was partially caused by heavier exploitation of age group II and III fish in 1958 and 1959. This trend must be stopped if the trout is to be maintained from natural reproduction.

Spawning mortality must be considered with the introduction of a minimum size limit. Ball and Cope (1961) found an average spawning mortality of 48 percent and stated that initial spawners made up most of each spawning run. Spawning mortality is undoubtedly the main source of natural mortality for the catchable-size stock. For efficient exploitation, therefore, it may appear desirable to catch as many fish as possible before spawning. The biological data conflict on this subject. On one hand, the data on sexual maturity suggest that essentially all trout are mature at age IV. On the other hand, fish of age group V exceeded 50 percent of the spawning runs in some streams for several years and rarely amounted to less than 25 percent of the total in any spawning run. Ball and Cope (1961) reported that repeat spawning is four times as common in alternate years as in consecutive years, so we must assume that some trout do not mature until age V, as suggested by Bulkley (1961). The preservation of a moderate number of age group V fish for spawning purposes is necessary, therefore, to maintain suitable spawning stocks. The low spawning runs in Pelican, Arnica, and Chipmunk Creeks in 1960 were caused partially by a lack of age group V fish. The management of this stock according to equilibrium yield will allow escapement of more spawners than necessary when several strong year classes are produced consecutively, but this sacrifice is necessary to allow escapement from weak year classes.

Reduction of creel limit

A reduction of the creel limit from 3 to 2 fish appears to be the simplest way to reduce the catch. A reduction in the creel limit can theoretically reduce the total catch, distribute the catch among more fishermen, or accomplish both. A reduction in total catch is expected under the assumptions that fishermen who consistently catch the creel limit cannot keep as many fish and the low creel limit will not attract as many fishermen from nearby states to Yellowstone. The catch will not be reduced significantly if a reduction in catch by the more skilled fishermen merely provides additional fish for the less skilled anglers or if the fishing pressure increases. A creel limit reduction will not influence all segments of the sport fishery on Yellowstone Lake equally; the probable effects on the shoreline fishery, boat fisheries, Fishing Bridge fishery, and total catch are discussed below.

Shoreline fishery.—In 1953, the creel limit was reduced from 5 to 3 fish, and the fishing season on the lake was opened 2 weeks later. Cope (1957a) examined the shoreline census and reported that more fish were caught under the 3-fish limit in 1953 than under the 5-fish limit in 1952. He concluded that the change in regulations resulted in a redistribution of the shoreline catch so that a larger percentage of the fishermen caught fish than before. It is possible that much of this redistribution was the result of a change in availability of the stock or in angling efficiency. There was an increase in availability from 1952 to 1953 as shown in figure 2. The transition to spinning gear was probably not sufficiently abrupt to cause all of the change in catch distribution. We expect that both the reduced creel limit and the increased availability contributed to the change.

Some effects of reduced creel limits on distribution of the catch among shoreline fishermen can be projected from catch

data collected from 1951 to 1960 (table 15). One phase of the shoreline census involves direct observation of fishermen to record their catch and the length of their daily fishing trip. Many fishermen are observed for their entire fishing day, but some move out of the observation area to fish elsewhere. Consequently the data are not total daily catches per fisherman, but catches per fisherman while under observation. This difference does not affect comparisons of catch distribution among years. In 1951 and 1952, one-fourth of the observed fishermen caught one or more fish each. The proportion of successful fishermen (those with one or more fish) increased to one-third in 1953 and was usually about 40 percent in ensuing years. Mean catch per fisherman actually increased with the smaller creel limit, probably owing mostly to increased angler efficiency through the introduction of spinning gear. From 1953 to 1959 there were more fishermen who caught a limit of 3 fish than those who caught only 2 fish. In 1960 this relation was reversed; the mean catch per fisherman dropped to a new low and the percentage of fishermen who caught no fish increased. The pattern established in 1960 reflected the depleted condition of the stock from overfishing. The total catch continued to increase until 1959 as shown in table 3. Thus the reduction in creel limit in 1953 had little influence on the total catch, since the fishing pressure rose from 1953 to 1960. A reduction in the creel limit will not influence the total shoreline catch greatly, unless it reduces the incentive to fish more than it is possible to foresee.

Boat fisheries.—Boat fishermen are more effective than shoreline fishermen as shown in the catch-per-man-hour data in table 4, and in the high catch-per-angler-day data in table 16. The catch per angler-day would be still higher if boat anglers kept all the fish they caught. As a reduced creel limit will not influence all boat fishermen the same, the various segments of the boat fishery are discussed separately.

The rental rowboat fishery is almost entirely limited to inshore areas within a few miles of each boat dock; the boats are small, and there are few outboard motors available for rent. The catch from this fishery dropped when the creel limit was reduced from 5 to 3 in 1953, but there was a gradual increase to 1957 and then a leveling-off until 1959. The total catch has never been restored to the 1952 high of 74,761 fish, in spite of the fact that the catch per angler-day has not changed to a great degree. A reduction in the creel limit will mean more fishing trips per rental boat, but the average trip will take less time. Some reduction in the catch by the rental boat fishery can be expected.

The catch of the guide-boat fishery reached a maximum of 46,550 fish in 1956 and has not been below 32,000 since 1954. This fishery is limited both by the number of available boats and by the fact that few anglers like to pay the higher costs of guide service. We do not expect this

TABLE 15.—*Percentage distribution of fishermen according to number of fish caught while under observation by census clerks, by years, 1951 to 1960*

Year	Number of fishermen observed	Percent of fishermen who caught—						Mean catch per fishermen
		0 fish	1 fish	2 fish	3 fish	4 fish	5 fish	
1951	533	75.8	10.1	5.6	3.0	1.3	4.3	0.458
1952	819	74.3	11.8	5.5	3.2	1.8	3.3	.561
1953	1,041	63.6	12.8	9.2	14.4	----	----	.744
1954	1,146	56.2	18.5	12.1	13.2	----	----	.823
1955	1,068	48.4	15.3	15.1	21.2	----	----	1.091
1956	880	63.2	16.9	9.7	10.2	----	----	.669
1957	722	60.5	17.9	9.0	12.6	----	----	.737
1958	565	59.5	14.5	11.0	15.0	----	----	.815
1959	1,377	59.7	20.3	9.9	10.1	----	----	.704
1960	1,158	71.6	16.1	7.3	5.0	----	----	.457

TABLE 16.—*Estimated angler-days, catch, and catch per angler-day for specified segments of the fishery on Yellowstone Lake, by years, 1950 to 1961*

Fishery segment	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961
Shoreline: [1]												
Angler-days	50,260	114,743	110,997	82,447	71,088	87,156	115,931	86,060	90,363	158,173	123,786	133,534
Catch	55,370	48,966	53,423	64,116	71,919	97,831	65,383	63,286	81,210	140,102	65,539	98,954
Catch per angler-day	1.10	0.42	0.48	0.78	1.01	1.12	0.18	0.73	0.90	0.89	0.53	0.74
Rental rowboats:												
Angler-days	37,488	39,633	35,523	28,216	28,150	31,651	28,081	37,783	37,009	36,449	26,154	33,501
Catch	55,123	60,993	74,761	38,772	39,969	47,986	47,765	61,350	56,552	66,281	41,266	53,362
Catch per angler-day	1.47	1.54	2.10	1.37	1.42	1.52	1.70	1.62	1.53	1.82	1.58	1.59
Guide boats:												
Angler-days	6,523	7,005	6,605	9,022	11,669	15,004	18,107	17,031	16,715	14,733	13,295	18,348
Catch	28,228	29,449	27,449	23,592	32,400	41,484	46,550	43,436	36,802	38,996	34,854	46,433
Catch per angler-day	4.33	4.20	4.16	2.61	2.78	2.76	2.57	2.55	2.20	2.65	2.62	2.53
Private trailer boats:												
Angler-days	13,603	18,984	25,255	21,413	21,227	33,237	46,701	48,299	61,002	55,407	53,159	49,363
Catch	50,377	54,857	75,457	50,118	51,222	80,270	110,937	115,141	149,667	124,421	126,109	93,632
Catch per angler-day	3.70	2.89	2.99	2.34	2.41	2.42	2.38	2.38	2.45	2.25	2.37	1.90
Private cruisers: [2]												
Catch	4,500	5,052	9,322	13,887	13,351	12,320	15,462	13,806	14,800	16,696	18,513	15,794
Fishing Bridge: [2]												
Catch	6,417	8,938	4,865	5,388	7,072	6,165	4,124	4,136	9,996	6,971	8,617	4,419
Total catch	200,015	208,255	245,277	195,873	215,933	286,056	290,221	301,155	349,027	393,467	294,898	312,594

[1] Data of shoreline actually represents number of "angler stops" rather than "angler days" as explained in Moore, Cope, and Beckwith (1953). True estimates of angler-days are lower than shown.
[2] Angler-day data not available.

fishery to expand, because many of the anglers who formerly used guide service have purchased their own boats, and a lower creel limit may further reduce the incentive to pay for guide services. As suggested in table 16, most guide-boat anglers had limit catches under either a 5-fish or a 3-fish limit. A reduction in the creel limit will reduce the guide-boat catch significantly.

The greatest increase in catch during the study period was in the trailer-boat fishery (table 16). The catch from this fishery dropped when the creel limit was first reduced to 3 fish, but the catch has continued to rise since 1954 owing to increased angling effort. This is coincident with a national boating trend. Trailer-boat fishermen are effective anglers, and they can reach lightly exploited areas. A reduction in the creel limit will reduce the catch per angler-day, but if the fishing pressure from boats continues to increase, the total catch will not drop. The new boating facilities being constructed at Yellowstone Lake may encourage more boats, but a lower creel limit may discourage many boat fishermen from nearby States. A National Park Service survey revealed that 90 percent of the boats launched on Yellowstone Lake were used primarily for fishing. One influence of a reduction of the creel limit will be to lower the "meat fishing" incentive that has been common among some trailer-boat anglers.

The private-cruiser fishery refers to the large private boats docked at Yellowstone Lake the entire fishing season. The catch from these boats has increased at a moderate rate. A reduced creel limit will undoubtedly decrease the total catch from these boats since limit catches are common. The possible closure of the south arms of Yellowstone Lake to motor-propelled boats may cause a further reduction in the number of boats in this fishery since these boat owners prefer the isolated portions of the lake.

Fishing Bridge fishery.—The Fishing Bridge catch is governed by the number of fish in the spawning runs which pass under the bridge, since fishing pressure is almost always at the maximum. The fishery is controlled by the limited space on the bridge for anglers and not by the creel limit. As soon as one fisherman completes fishing another moves into his place and commences fishing. A reduced creel limit will not reduce this catch.

Total catch.—Analyses by fishery segments reveal that a creel limit reduction will lower the total catch, but it is not the final answer to equilibrium-yield management. If fishing pressure continues to increase, the catch will again exceed equilibrium yield in a few years. The biggest reduction in catch may result from the reduced incentive for fishermen from nearby States to come to Yellowstone for the express purpose of fishing for meat. This type of use has been decreasing in recent years, but we expect that a limit of 2 fish will be still more effective in this regard.

Fishing for fun

Fishing for fun is a management concept which emphasizes the recreational values of angling in contrast to maximum production from a fish stock. In the Great Smoky Mountains National Park fishing-for-fun experiment, only "trophy" fish can be retained, although there is no limit on the number of trout that can be caught and released (Lennon and Parker, 1960). Only single-hook artificial lures may be used. The populations in these fishing-for-fun streams cannot withstand heavy fishing pressure if all captured trout are kept.

The fishing-for-fun concept was introduced at Yellowstone Lake by the National Park Service in 1961 on a voluntary basis. Anglers were encouraged to use barbless hooks and to retain only those cutthroat trout that were badly injured. The creel limit of 3 fish was retained. There is neither a need nor is it desirable to carry the concept to the degree mentioned for the Great Smoky National Park. Yellowstone Lake is excellent trout habitat, and the fish population can withstand a large annual catch. Also, "trophy" fish will never be produced in this lake because of the growth rate and high spawning mortality.

The success of the Yellowstone program depends upon angler cooperation rather than regulation. Data were collected in 1961 to determine angler acceptance of the program and the degree of hooking mortality that could be expected from catching and returning fish to the water. Analysis of interviews with 2,661 shoreline and boat anglers revealed that (1) 82 percent of the anglers interviewed were successful, (2) 80 percent of the successful anglers kept all the fish they caught, (3) 65 percent of the anglers who returned fish still kept their limits, and (4) only 3.9 percent of the successful anglers returned all fish captured. Many anglers have always released trout caught in Yellowstone Lake, and it was not possible to determine how much influence the fishing-for-fun campaign had on the fishing public.

The 1961 interview data indicate that anglers used the program primarily as an excuse to continue fishing after catching their limits. If this interpretation of fishing-for-fun becomes established, the program may induce additional mortality on the stock from hooking, with no reduction in total catch. Preliminary hooking studies conducted during 1961 revealed that mortality from catching and releasing trout with standard spinning gear and treble-hook spoons was negligible (0.7 percent) during the spawning season but reached significant proportions (21.3 percent) in midsummer.

Evaluation of the fishing-for-fun program should continue because it is not possible to predict its effects on management of the fish stock at this time. The program as presently functioning is not an effective tool for reducing the catch.

Effects of regulations

It is not possible to predict what the annual catch would be under any of the regulations mentioned. Variations in effective fishing effort and fishing pressure will require continuous evalution. The knowledge of the equilibrium yield of Yellowstone Lake will never mean that regulations to attain that yield can be estab-

lished a year in advance of an angling season unless some quota system is possible to administer. Its greatest value is that it sets a goal on the number of fish that can be removed and allows the fishery manager to distribute the catch or fishing pressure as considered expedient.

The principal aim of fishery management on Yellowstone Lake should be to provide the maximum number of fishing hours or trips and not to derive the maximum possible yield in pounds or numbers of fish. There is the problem in arriving at a happy medium between attaining maximum use of the resource and avoiding extended overexploitation of it. A few anglers do not care about keeping any fish, but the majority wish to retain a few trout for eating. Management must be directed at the majority if we are to provide the maximum number of fishing trips. The question is what regulations are necessary to prevent overfishing on Yellowstone Lake without reducing the fishing incentive for the majority of anglers. For the present, a 2-fish creel limit and a 12-inch minimum size limit should essentially accomplish both aims. Only continuous evaluation of the fishing pressure and the condition of the stock will answer this question fully.

Redistribution of fishing pressure

The present calculated equilibrium yield is below the potential equilibrium yield for Yellowstone Lake because of the poor distribution of fishing pressure. If Yellowstone Lake were to be managed for fishing purposes only, additional access to the southern areas of the lake would be necessary. The National Park Service is considering a plan to close the two southern arms of the lake to all motor-propelled boats to perpetuate wilderness values. A partial closure was carried out in 1961. If these arms are closed, fishing pressure in the southern area will likely be lower in the future than at present.

The effects of this closure cannot be accurately predicted. It may shift additional fishing pressure to the northern area and West Thumb which would require a lower equilibrium yield for the lake than the present estimate of 325,000 fish. Present methods of measuring changes in the stock are adequate to determine the degree of exploitation in these two areas, and continuous measurement of the stock condition is imperative.

Interspecific competition

The longnose sucker and redside shiner must be considered possible detriments to cutthroat trout production in Yellowstone Lake. Several workers (Bassett, 1957;[5] Rawson and Elsey, 1948; Larkin and Smith, 1953) found that these species adversely influenced trout populations. Competition may be expected to increase as the density of the trout population is reduced. The only long-term sampling of suckers of Yellowstone Lake has been in fish traps where every sucker was killed. Trap counts have decreased in recent years, but this decrease is not necessarily representative of the lake sucker population. Biesinger[6] studied the distribution and degree of competition between trout and introduced species in Yellowstone Lake. The sucker is distributed widely and presently occupies all the suitable habitat. The best sucker habitat is in the highly productive littoral zone which is heavily used by trout, and suckers feed on essentially the same food organisms as trout. The influence of suckers on the cutthroat trout stock is not clear. Available data are insufficient for determining whether the decrease in trout density in heavily used fishing

[5] "Further life history studies of two species of suckers in Shadow Mountain Reservior, Grand County, Colorado," by Howard M. Bassett. Unpublished master's thesis, Colorado State University, 1957, 112 pp.

[6] "Studies on the relationships of the redside shiner (*Richardsonius balteatus*) and the longnose sucker (*Catostomus catostomus*) to the cutthroat trout (*Salmo clarki*) population in Yellowstone Lake," by Kenneth Biesinger. Unpublished master's thesis, Utah State University, 1961. 90 pp.

areas has resulted in an increase in suckers, although growth rates of suckers did not increase with a decrease in trout density.

The redside shiner distribution is more limited than that of suckers, possibly because the shiners were introduced into Yellowstone Lake more recently. Their principal habitat is the shallow lagoons and a few tributary streams in the northern area. They share the habitat with small cutthroat trout, and their feeding habits are similar to those of small trout. No redside shiners have been collected in the limnetic zone of the lake, and none were found in trout stomachs. Biesinger [7] concluded that competition is more severe between juvenile cutthroat trout and longnose suckers or redside shiners than between the adults. Lake Chubs are confined to a few lagoons and streams and are so rare that competition must be insignificant. The native longnose dace is confined to a few streams, and no competition is evident.

Yellowstone Lake is deeper and has less littoral habitat than many of the other lakes where severe competition between suckers and trout has been found. It is possible, however, that both the longnose suckers and redside shiners will expand their numbers if the cutthroat trout stock is further reduced. Partial control methods such as spot-poisoning or trapping could be tried, but there is reason to believe that a well-managed stock of cutthroat trout is the best answer.

Planting

Yellowstone Lake can produce excellent angling with natural reproduction, and can be managed on this basis. Planting would simplify management in some cases and possibly would increase the yield. Large numbers of eggs, fry, and advanced fry were stocked in Yellowstone Lake and tributaries before 1951 (table 1). All plantings consisted of eggs or fry from Yellowstone Lake spawners. The survival rate of these plantings was not compared with the survival rate of wild fish, but there is no doubt that the plantings were beneficial in several tributary streams. In Pelican Creek, no escapement was reported from 1936 to 1944,[8] and year classes produced during that period must have resulted from plantings; the strong and unnaturally stable spawning runs from 1945 to 1948 enumerated in table 10 must have been the result of plantings. Several substantial spawning runs were established from plantings in small streams, such as Hatchery Creek. The Hatchery Creek runs have disappeared without stocking. There is also no evidence that the egg-collecting operation carried out up to 1953 was influencing the lake stock, although the continuous planting program and the low fishing pressure during the years of heavy egg-collecting prevent accurate evaluation.

From 1945 to 1950 a good escapement was allowed in all sampled streams, but small plantings were made in some streams to supplement natural reproduction. All planting of Yellowstone Lake or tributary streams was terminated after 1950, except for two small experiments in Arnica Creek in 1954 and 1955. The year classes from 1946 to 1950 were the result of plantings plus natural reproduction, and all year classes after 1950 were entirely the result of natural reproduction. From the variations in strength of year classes shown in figure 6, it is doubtful whether the small supplemental plantings from 1945 to 1950 benefited the stock. The plantings in Arnica Creek in 1954 and 1955 did not appear to influence year-class strength in this stream. Note, however, that the spawning runs in table 11, apparently derived entirely from plantings (1945 to 1948), fluctuated less than spawning runs derived from natural reproduction. There is evidence, therefore, that the use of fry

[7] See footnote 6.

[8] Letter from W. A. Dunn, Superintendent, Yellowstone Hatchery, to Regional Director, U.S. Fish and Wildlife Service, dated March 8, 1945.

plantings in streams to supplement artificial reproduction when environmental conditions in spawning streams are not suitable would be an excellent management tool to offset the great fluctuations in year-class strength that presently occur. Any fry plantings contemplated should be made in early August or after the high water period.

Although fry stocking may alleviate the occurrences of poor year classes in some streams, a fingerling stocking program would have greater benefit to the entire lake stock. Most planting experiments (Curtis, 1951) have found a higher survival rate for fingerlings than fry, and we would expect similar results in Yellowstone Lake. Survival rate of wild fish in the fingerling size range in Yellowstone Lake is known to be high. The use of hatchery-reared fingerlings would simplify management, since natural reproduction could be partially desregarded and overexploitation of prespawners would not be as serious.

Fingerling plants in management would be costly, and the lake can be managed rather easily with an average equilibrium yield of about 325,000 trout without stocking. The lake production for the angler could be increased considerably by fingerling stocking, but the esthetic value of fishing a "natural" trout population would be partially lost. A stream fry-planting program can be carried out at low cost, since the fry would have to be fed only a few weeks, and such a program would not reduce the natural aspects of angling as much as fingerling stocking. In any case, only eggs of cutthroat trout from Yellowstone Lake should be used in any stocking plan, to preserve one of the few native stocks of this species in the United States.

YELLOWSTONE RIVER FISHERY

The 15-mile section of the Yellowstone River from a point 300 yards below Fishing Bridge to the Upper Falls furnishes much excellent angling, and the management of this fishery is closely related to management of the lake stock. Regulations should be similar for Yellowstone Lake and this section of the river.

The total catch from the river rose from 19,729 in 1950 to a maximum of 81,724 in 1958, and has fluctuated to a greater degree than that of the lake fishery (table 17). The catch per man-hour was lower from 1951 to 1953 than in recent years, and the higher catch per man-hour after 1953 has been attributed partially to the greater use of spinning gear. The poor catch in 1956 was due to high water (table 17). The best fishing success was recorded in 1955 and was associated with low water. The biweekly catch per man-hour is always greatest at the opening of the season and decreases rapidly toward the end of the season. This trend takes place because the river fishery is almost wholly dependent upon a spawning migration.

TABLE 17.—*Estimated catch and catch per man-hour for Yellowstone River fishery, by years, 1951 to 1959*

[With mean monthly discharge of river, in cubic feet per second, for June and July]

Year	Catch	Catch per man-hour	Discharge	
			June	July
1951	19,729	0.236	4,204	4,825
1952	20,603	.225	4,796	3,788
1953	27,932	.346	2,617	3,798
1954	35,912	.478	3,916	5,040
1955	63,701	.649	2,851	3,455
1956	21,907	.325	6,640	5,172
1957	47,762	.446	4,031	4,605
1958	81,724	.500	3,361	2,460
1959	67,799	.427	3,285	4,387

Some data on the relations of the river stock to the lake stock were determined from tagging fish in the Cascade area (5 miles downstream from Fishing Bridge) of the Yellowstone River in 1951, 1952, and 1953 (Ball and Cope, 1961). Most tagged fish were recovered in the river or in the

Fishing Bridge area when they were captured the same year as they were tagged. A relatively large number captured the year after tagging were caught in the lake. Few fish tagged in Pelican Creek or near the Fishing Bridge campground were captured in the river below Fishing Bridge. This tagging study shows that many of the lake fish move down into the river below Fishing Bridge to spawn and then return to the lake. It is these fish which probably constitute most of the river fishery now. In addition, the river probably contains a small resident population.

From available data, we believe that sound management of the lake stock will automatically manage the river stock if similar regulations are in effect in the two areas. Overexploitation of the resident river stock will be compensated by immature fish produced from the spawning areas around and downstream from Fishing Bridge. The July 1 opening of the fishing season protects the spawning stock moving into this river area for a sufficient part of the spawning season in most years. A reduction of the creel limit to two fish for the river will help to insure adequate seeding of this important spawning area. The minimum size limit of 12 inches recommended for the lake and river would also be of considerable value in protecting the river stock, because the river catch includes more small fish in the latter part of the season than the lake catch.

SUMMARY

This paper summarizes data collected from 1945 to 1961 on the biology of the cutthroat trout in Yellowstone Lake, fluctuations in the fish populations, catch, and management. The principal purpose is to establish a maximum equilibrium yield and to consider management with respect to equilibrium yield.

Biological investigation and fish culture are briefly reviewed. The life history of cutthroat trout in Yellowstone Lake and the ecology of the lake are summarized. The fish stocks from the northern area and West Thumb are considered separately.

The catch increased from 200,015 cutthroat trout in 1950 to 393,497 in 1959. Fishing pressure was more erratic than the catch and reached 526,728 man-hours in 1959. Catch per man-hour did not vary according to stock density and was not a reliable index of stock condition. Spawning concentrations, water levels, and fishing methods influenced catch per man-hour. Most of the trout caught from 1950 to 1961 fell within a 100-mm. range, and mean total lengths ranged from 336.7 to 357.8 mm. Age groups III, IV, and V comprised most of the catch. The northern area included more older fish during the early part of the season than West Thumb; the two areas were similar after the middle of July. Estimated percentages of sexually mature fish in the catch ranged from 64.3 to 84.8.

Growth rate increased from 1950 to 1956, but leveled off from 1956 to 1959. Optimum growth for the catchable stock was reached in 1956.

Spawning runs in six streams were measured from 1945 to 1961. General characteristics of spawning runs are described. Changes in the number and mean age of spawners are related to the increased catch. Arnica Creek runs fluctuated irregularly, but the low runs in 1959, 1960 and 1961 were attributed to overfishing in West Thumb. Pelican Creek has the largest spawning run of the streams measured, and its spawners are subjected to the greatest fishing pressure. The 1960 spawning run was depleted by the increased catch in the northern area. The 1961 run indicated that some recovery

of the fishery occurred due to the reduced catch in 1960.

Clear and Cub Creek data are not complete, but a downward trend in number of spawners has been related to the increased catch. Chipmunk and Grouse Creeks are isolated, and the spawners from these streams are subjected to the least fishing pressure of the sampled streams. These latter streams have a larger number of fish of age group V or older than other streams, and since many age group V are probably initial spawners, the spawning runs can be depleted by fishing more easily. The low 1960 and 1961 runs are definitely attributed to overfishing.

Accurate mortality data could not be computed, but total instantaneous mortality rates are calculated by year class for fish of age groups IV and V to show gross changes. Excessive mortality occurred in the northern area when the catch exceeded 200,000 trout, and in West Thumb when the catch exceeded 100,000.

Year classes in the northern area were strongest in 1945, 1949, 1953, and 1957. The West Thumb catch was more irregular than the northern area catch, but strong year classes were produced in 1947, 1952, 1953, 1955, and 1957.

Methods for determining maximum equilibrium yield are described. Three stages of exploitation are defined for the Yellowstone stock; these stages consider growth rate, spawning runs, and age groups in the catch. Overfishing commences in the second stage of exploitation. The estimated maximum equilibrium yield averaged 325,000 fish and may range from 290,000 to 340,000 fish with the present distribution of fishing pressure.

Various measures are discussed for equilibrium yield management. Control of fishing pressure is the most precise but is not practical. Delaying the fishing season until July 1 would be quite unpopular, even though it would assure survival of more fish through spawning. A minimum size limit of 12 inches is recommended to reduce and redistribute the total catch, and to protect prespawning fish. A reduction in creel limit will reduce the total catch among some fishermen, but its greatest value may be to reduce the incentive to fish for food. The fishing-for-fun management system is discussed. Angler interview data suggest that a voluntary system is not a positive measure for reducing the catch. Hooking experiments showed that additional mortality will be inflicted on the fish population by catching and releasing fish after the spawning season. The effects of all regulations should be observed closely.

Closure of the south arms of Yellowstone Lake to motor-propelled boats may result in a lower equilibrium yield for the lake.

Competition from the longnose suckers and redside shiners may increase, but good trout management and the small amount of sucker and redside shiner habitat can prevent a population explosion of these introduced species.

The planting of cutthroat trout fry to prevent the occurrence of poor year classes is considered a possible management tool. Fingerling stocking would simplify management but is not recommended at this time.

The Yellowstone River fishery is reviewed. It is closely connected with the lake population, and wise managment of the lake should automatically manage the river population. Similar regulations should be in effect on both areas.

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Appendix A—DISTRIBUTION OF FISHING

Creel census information has been collected by segments, and the methods for determining the percentage of fish from each segment that came from the northern area or from West Thumb is described below: The methods for conducting the census were described by Moore et al. (1952).

Rented rowboats

The rented rowboats from Fishing Bridge and Lake Dock are used entirely in the northern area and the entire catch from these docks is known to come from the northern area. The rented boats from West Thumb dock fish entirely in the West Thumb area.

Fishing Bridge

The entire catch is from the northern area.

Guide boats

Fishing Bridge guides from 1950 to 1953 fished in the southern area as follows: 1950, 4.5 percent; 1951, 12.1 percent; 1952, 1.2 percent; 1953, 4.0 percent. The remaining catch came from the northern area.

Lake guides fish principally in the northern area, but a census of guide boats showed that 3 percent of the catch came from the southern area from 1954 to 1960. The remainder, or 97 percent, was from the northern area.

West Thumb guides fish mostly in West Thumb, although an average of 20 percent, as determined from guide boat records, fish in the southern area that adjoins West Thumb. This percentage varies slightly annually, but accurate records are not available for all years, and we have assumed that 80 percent of the catch comes from West Thumb and 20 percent from the southern area.

Private boats

The trailer boat fishery is the most difficult to break down accurately into areas. Boat card data have been used to determine where boats were launched and the total catch per launching area. All boat launching areas are in the northern area and West Thumb. The increase in average horsepower per boat in recent years has enabled boats to reach more inaccessible areas than was possible in previous years. Consequently there has been an increase in fishing pressure in the southern area. The percentages in table A–1 give the estimated distribution of the catch by areas from 1950 to 1961 and take into account all these known changes.

The cruiser fishery includes the largest boats on the lake, and all are anchored the entire fishing season at Lake, Fishing Bridge, and West Thumb docks. These boats fish mostly in the southern area. The estimated distribution of the cruiser catch by areas is: northern, 15 percent; West Thumb, 10 percent; and southern, 75 percent.

Lake shoreline

Accurate data are available on the shoreline fishery since fisherman counts are made three times a week along the entire accessible shoreline. The shoreline catch was divided between the northern area and West Thumb from 1950 to 1961 as shown in table A–2.

APPENDIX TABLE A–1.—*Estimated percentage distribution of trailer boat catches, by area, 1950 to 1961*

Year	Percent of catch from—		
	Northern area	Southern area	West Thumb area
1950	80.0	2.0	18.0
1951	79.0	1.0	20.0
1952	65.5	3.8	30.7
1953	65.0	4.2	30.8
1954	64.2	4.8	31.0
1955	64.2	4.8	31.0
1956	63.5	5.5	31.0
1957	62.2	6.8	31.0
1958	62.8	7.2	30.0
1959	61.3	8.2	30.5
1960	61.0	8.3	30.7
1961	61.0	8.3	30.7

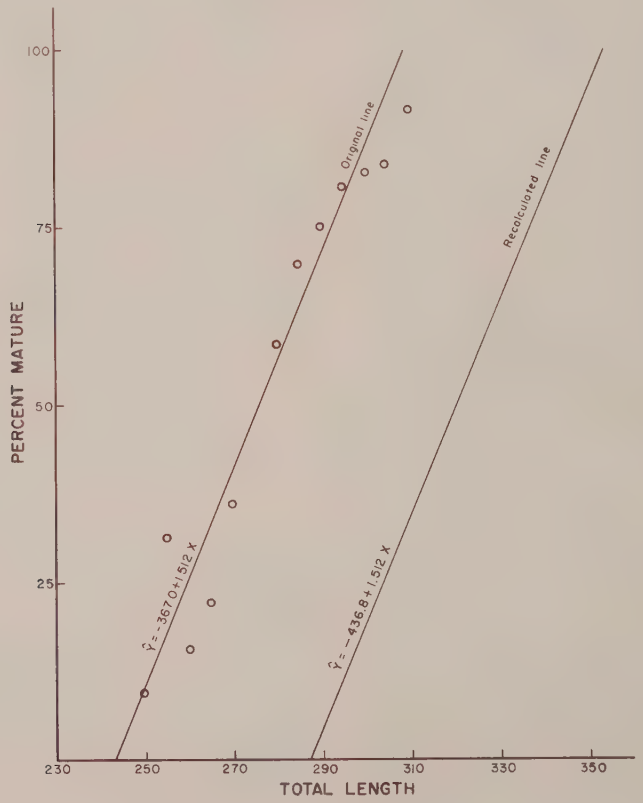
APPENDIX TABLE A–2.—*Percentage distribution of shoreline catches, by area, 1950 to 1961*

Year	Percent of catch from—	
	Northern area	West Thumb area
1950	72.7	27.3
1951	71.5	28.5
1952	77.7	22.3
1953	75.3	24.7
1954	75.1	24.9
1955	76.6	23.4
1956	74.6	25.4
1957	75.9	24.1
1958	71.9	28.1
1959	76.4	23.6
1960	80.5	19.5
1961	74.1	25.9

Appendix B—MATURITY OF FISH IN CATCH

A sample of 1,055 fish from the catch at Fishing Bridge dock in 1953, 1954, and 1960 and at West Thumb dock in 1960 was examined to determine the maturity of fish in different length groups up to July 15. A mature fish is one which has spawned in previous years or has spawned or will spawn in the season of capture. The differences between sexes were so minor that they have been combined. From these data, no fish below 250 mm. was mature and no fish above 305 mm. was immature. Data for each year gave the same results. A regression line was calculated from combined data to determine the expected percentage of mature fish in each 5-mm. length group in the 245 to 310 mm. range (fig. B–1).

Stage of maturity was difficult to measure after July 15, but growth is rapid during the angling season and this regression line could not be applied accurately to the entire season's catch. Many trout captured in August measuring 325 mm. total length were known to be immature. Bulkley (1961) studied growth rates of cutthroat trout, but he was not able to measure seasonal periodicity of growth. To compensate for growth we assumed that half the season's growth will be completed by August 1. One-half of the mean annual growth



Appendix figure B–1.—Relation of maturity to total body length in millimeters. Original line from catch data collected before July 15 in 1953, 1954, and 1960. Recalculated line includes adjustment for expected seasonal growth.

increments between age groups II and III and age groups III and IV, or 46 mm., has been considered the expected growth rate up to August 1. The regression line calculated earlier was moved 46 mm. to the right. Actually most of the catch is made during June and July, and the use of this regression line may indicate a larger percentage of immature fish than is true. From our knowledge of the sizes and ages of fish entering the spawning runs, the second regression line represents the average maturities of the catch accurately. The percentage of mature fish in each 5-mm. length group was taken from the recalculated regression line and applied to the length distribution of the catch each year (table B–1). The sum of the mature fish in all length groups was then divided by the total sample to obtain the percent of mature fish in the catch.

APPENDIX TABLE B–1.—*Percent of mature fish by 5-millimeter length groups as taken from regression line on figure B–1*

Length group	Percent mature
285 mm	0.0
290 mm	4.3
295 mm	11.9
300 mm	19.6
305 mm	27.2
310 mm	34.8
315 mm	42.4
320 mm	50.0
325 mm	57.6
330 mm	65.2
335 mm	72.8
340 mm	80.4
345 mm	88.0
350 mm	95.6
355 mm	100.0

Appendix C—GROWTH INCREMENTS

APPENDIX TABLE C–1.—*Increments of growth of age groups II to VI from Fishing Bridge, and deviations from mean growth, by calendar year, 1946 to 1960*

[In millimeters; number of fish in parentheses]

Age group and year of life	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	Mean
Age group II:																
Year 2				88		101	80	159	150	104	140		113	139		119.30
Year 1			46		56	47	49	49	50	47		52	45			49.00
			(3)		(14)	(21)	(17)	(9)	(2)	(5)		(15)	(15)			
Age group III:																
Year 3		70		91	120	81	96	89	95	86	94	86	98	98	103	92.84
Year 2	117		86	48	96	108	99	91	117	87	90	81	121	110		96.23
Year 1		47	44	47	44	44	44	49	44	44	44	47	47			45.42
	(11)	(18)	(48)	(145)	(76)	(43)	(60)	(44)	(44)	(29)	(24)	(60)	(46)			
Age group IV:																
Year 4		73		69	80	88	69	85	86	87	94	96	82	105	109	86.38
Year 3	83		87	97	92	112	101	109	87	99	96	100	86	88		95.15
Year 2		60	47	72	76	60	57	83	76	74	54	92	93			70.33
Year 1	45	43	45	45	46	44	44	45	44	46	45					44.75
	(110)	(121)	(184)	(110)	(69)	(80)	(103)	(191)	(136)	(39)	(52)	(70)				
Age group V:																
Year 5		93		74	82	75	80	75	79	77	76	68	81	68	71	76.85
Year 4	45		84	68	78	74	93	77	78	84	99	104	90	94		82.15
Year 3		92	102	94	95	80	94	91	99	92	106	82	96			93.58
Year 2	54	37	40	50	56	57	58	50	55	51	94	79				56.75
Year 1	43	45	44	44	45	44	43	44	46	47	43					44.64
	(129)	(110)	(126)	(90)	(123)	(80)	(110)	(113)	(20)	(23)	(23)					
Age group VI:																
Year 6				54	52	57	44		52		65	46		51		52.63
Year 5			82	79	80	88		86		97	93		94			87.37
Year 4		65	75	68	77		73		92	77		75				75.26
Year 3	94	84	83	96		93		112	93		135					98.75
Year 2	36	48	54		38		22	45								40.50
Year 1	43	43		44		43	44									43.40
	(16)	(22)		(26)		(7)	(12)		(2)							
Percentage deviation from mean, all ages	−4.06	−10.73	−3.09	−5.69	+1.21	−2.04	−2.13	+0.43	+1.93	+0.72	+6.30	+4.46	+9.24	+6.53	+15.54	

APPENDIX TABLE C–2.—*Increments of growth of age groups II to VI from West Thumb, and deviations from mean growth, by calendar year, 1946 to 1960*

[In millimeters; number of fish in parentheses]

Age group and year of life	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	Mean
Age group II:																
2				122		113	127	128	107				140	144	116	124.62
1			50		50	56	50	49				48	50	56		51.10
			(27)		(14)	(7)	(28)	(25)				(4)	(18)	(4)		
Age group III:																
3				86	101	104	82	93	93	97	87	85	85	93	92	91.50
2			89	88	97	97	83	90	108	97	104	102	100	117		97.65
1		45	49	51	49	48	46	53	44	44	46	47	48			47.50
		(145)	(124)	(166)	(107)	(130)	(118)	(89)	(39)	(23)	(28)	(62)	(47)			
Age group IV:																
4		85		87	84	82	90	88	96	89	91	104	106	105	111	93.69
3	113		99	98	96	103	101	95	82	99	104	81	95	86		96.30
2		61	63	65	66	59	63	85	75	65	89	81	95			72.25
1	46	45	47	46	45	44	49	43	44	44	47	46				45.50
	(105)	(149)	(189)	(155)	(200)	(145)	(135)	(137)	(120)	(56)	(61)	(70)				
Age group V:																
5		85		70	76	76	80	85	81	72	85	83	82	69	75	78.38
4	70		87	82	75	72	73	76	82	84	90	98	91	99		83.00
3		98	91	86	90	103	94	90	96	99	114	115	92			97.32
2	48	49	51	45	27	45	60	47	52	53	69	69				51.25
1	44	44	43	43	43	46	43	44	45	44	48					44.27
	(78)	(111)	(70)	(88)	(70)	(65)	(105)	(85)	(16)	(17)	(24)					
Age group VI:																
6				51	55	52	44	50	62		52	55		56		53.00
5			98	95	88	95	90	78		70	102		117			92.55
4		62	72	75	70	70	61		97	55		81				71.44
3	88	84	115	79	95	84		98	88		72					89.22
2	26	26	45	22	36		47	56		36						36.75
1	47	44	43	43		43	44		43							43.85
	(18)	(18)	(9)	(9)		(6)	(4)		(4)							
Percentage deviation from mean, all ages	−0.80	−5.64	−0.20	−5.65	−6.52	−4.80	−4.09	+0.38	+0.27	−2.28	+6.27	+5.43	+7.57	+6.11	+8.19	

Appendix D—YEAR-CLASS STRENGTH

APPENDIX TABLE D–1.—*Calculation of year-class strength from method of el-Zarka (1959) for northern area and West Thumb*

Area and year class	Age groups included	Sum, first year	Sum, second year	Mean	Difference	Percentage difference between years	Relative strength, first year	Final rank, first year
Norther area:								
1944–1945	VI-VII	10.7	13.5	0.7	2.8	23.1	0.0	−0.2
1945–1946	V-VI	50.7	39.7	12.1	−11.0	−24.3	23.1	22.9
1946–1947	IV-VI	77.6	63.5	45.2	−14.1	−20.0	−1.2	−1.4
1947–1948	III-VI	76.6	92.4	70.6	15.8	18.7	−21.2	−21.4
1948–1949	II-VI	93.4	111.7	84.5	18.3	17.8	−2.5	−2.7
1949–1950	II-VI	111.7	99.8	102.6	−11.9	−11.2	15.3	15.1
1950–1951	II-VI	99.8	87.0	105.8	−12.8	−13.7	4.1	3.9
1951–1952	II-VI	87.0	105.3	93.4	18.3	19.0	−9.6	−9.8
1952–1953	II-VI	105.3	113.0	96.2	7.7	7.1	9.4	9.2
1953–1954	II-VI	113.1	77.2	95.5	−35.9	−37.6	16.5	16.3
1954–1955	II-V	76.8	80.9	78.8	4.1	5.2	−21.4	−21.6
1955–1956	II-V	80.9	82.0	81.5	1.1	1.4	−16.2	−16.4
1956–1957	II-IV	70.5	101.3	85.9	30.8	35.9	−14.8	−15.0
1957							21.1	20.9
West Thumb:								
1944–1945	VI	4.0	2.2	3.1	−1.8	−58.1	0.0	58.3
1945–1946	V-VI	32.6	24.9	28.8	−7.7	−26.7	−58.1	0.7
1946–1947	IV-VI	49.7	67.5	58.6	17.8	30.4	−84.8	−26.0
1947–1948	III-VI	101.7	93.0	97.4	−8.7	−8.7	−54.4	4.4
1948–1949	II-VI	99.4	99.3	99.4	−0.1	−0.1	−63.1	−4.3
1949–1950	II-V	96.8	95.9	96.4	−0.9	−0.9	−63.2	−4.4
1950–1951	II-V	95.9	92.8	94.4	−3.1	−3.3	−64.1	−5.3
1951–1952	II-VI	94.9	122.4	108.7	27.5	25.3	−67.4	−8.6
1952–1953	II-VI	120.8	119.3	120.0	−1.5	−1.3	−42.1	16.7
1953–1954	II-VI	119.3	73.8	96.6	−45.5	−47.1	−43.4	15.4
1954–1955	III-VI	73.8	93.2	83.5	19.4	23.2	−90.5	−31.7
1955–1956	II-V	93.1	89.8	91.5	−3.3	−3.6	−67.3	−8.5
1956–1957	II-IV	75.9	90.2	83.1	14.3	17.2	−70.9	−12.1
1957							−53.7	5.1

Appendix E—CATCH CURVES

APPENDIX TABLE E–1.—*Estimated number of fish caught from northern area and from West Thumb, by age group, 1950 to 1961*

Calendar year	Age group II		Age group III		Age group IV		Age group V		Age group VI		Age group VII		All age groups	
	Northern area	West Thumb	Northern area	West Thumb	Northern area	West Thumb	Northern area	West Thumb	Northern area	West Thumb	Northern area	West Thumb	Northern area	West Thumb
1950	1,448	3,109	18,971	16,613	54,885	12,047	53,872	14,767	14,626	1,943	1,014	97	144,816	48,575
1951	2,960	833	19,980	17,657	50,320	21,199	53,724	11,094	19,980	1,146	1,036	156	147,999	52,085
1952	5,108	1,789	52,609	20,954	66,910	23,893	39,840	14,055	5,789	2,300	--------	894	170,255	63,885
1953	7,642	776	27,590	11,646	39,895	16,886	45,724	7,647	7,901	1,863	777	--------	129,529	38,819
1954	10,965	3,330	27,856	15,305	44,599	23,628	58,231	10,364	6,520	1,074	--------	--------	148,171	53,702
1955	5,749	5,323	38,521	25,049	51,553	30,841	79,150	14,872	16,673	1,957	--------	235	191,647	78,276
1956	14,643	--------	33,672	26,374	78,690	39,950	61,488	19,283	7,686	865	--------	--------	182,999	86,472
1957	2,624	645	23,058	12,443	100,292	43,690	57,738	33,459	3,749	1,936	--------	--------	187,462	92,174
1958	2,190	2,103	22,999	13,985	101,414	51,000	83,453	36,384	8,761	1,682	--------	--------	219,036	105,155
1959	20,275	1,523	50,062	23,669	136,169	79,676	43,554	12,186	250	117	--------	--------	250,310	117,171
1960	5,806	3,523	58,775	25,528	89,796	46,157	26,486	9,541	725	1,204	--------	--------	181,588	85,953
1961	1,730	1,651	51,513	26,318	116,864	57,491	22,104	11,557	--------	97	--------	--------	192,211	97,114

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Through a score of bureaus and offices the Department has responsibility for the use and management of millions of acres of federally owned lands; administers mining and mineral leasing on a sizable area of additional lands; irrigates reclaimed lands in the West; manages giant hydroelectric power systems; administers grazing and forestry programs on federally owned range and commercial forest lands; protects fish and wildlife resources; provides for conservation and development of outdoor recreation opportunities on a nationwide scale; conserves hundreds of vital scenic, historic, and park areas; conducts geologic research and surveys; encourages mineral exploration and conducts mineral research; promotes mine safety; conducts saline water research; administers oil import programs; operates helium plants and the Alaska Railroad; is responsible for the welfare of many thousands of people in the territories of the United States; and exercises trusteeship for the well-being of additional hundreds of thousands of Indians, Aleuts, and Eskimos, as well as being charged with resource management of millions of acres of Indian-owned lands.

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